BBSV

H. Kronis

Environment Canada

Environnement Canada

Ontario

Ministry of the Environment

CONFERENCE PROCEEDINGS NO.1 PHOSPHORUS REMOVAL DESIG

Phosphorus Removal Design Seminar
Conference Proceedings No.1

Research Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

BBSV

PHOSPHORUS REMOVAL DESIGN SEMINAR

May 28 - 29, 1973.

Toronto

CONFERENCE PROCEEDINGS NO. 1

This document may be obtained from -

Training and Technology Transfer
Division (Water)
Environmental Protection Service
Environment Canada
Ottawa, Ontario KIA OH3

Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue W.
Toronto, Ontario M4V 1P5

NOTICE

All materials and information contained in these CONFERENCE PROCEEDINGS are published in the exact form as presented to Environment Canada and the Ontario Ministry of the Environment by the seminar speakers. No attempt is made to edit, reformat or alter the material provided except where obvious errors or discrepancies have been detected. Statements and views presented are totally those of the speakers and do not necessarily reflect the views and policies of the Joint Committee of Environment Canada and the Ontario Ministry of the Environment. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

In response to the International Joint Commission recommendations, the federal government and the government of Ontario signed an important agreement in August, 1971. Under the terms of the Canada-Ontario Agreement on Great Lakes Water Quality, the two governments undertook to accelerate the construction of pollution control facilities in the Great Lakes Basin, and provide funding for treatability studies and research designed to improve pollution control technology. Six million dollars will be made available for this purpose over the period of the Agreement, from August, 1971 to December 31, 1975. Approximately half this fund is required for municipal phosphorus treatability studies.

The province of Ontario and Ontario municipalities are presently involved in a five-year program to control, by 1975, phosphorus discharges from more than 200 existing wastewater treatment plants serving some 4.7 million people. For the most critically affected areas of the province, permanent phosphorus removal facilities must be operational by December 31, 1973.

In view of this deadline and the fact that the development of design parameters for phosphorus removal facilities is in its infancy it became apparent that a seminar of this nature should be of considerable assistance to those involved in the design of these facilities.

The Phosphorus Removal Design Seminar held at the Skyline Hotel, Toronto, May 28 - 29, 1973, is the first such seminar to be convened under the Canada-Ontario Agreement on Great Lakes Water Quality. This seminar was intended to provide an exchange of information between consulting engineers and government personnel involved in the design and approval of phosphorus removal facilities at waste treatment plants. It is planned to hold a one day conference on October 16, 1973 to acquaint specifically municipal officials and others in the water quality field with this information.

These seminar papers should be useful as a reference for those who participated and those who did not have an opportunity to attend this seminar.

The papers presented at the seminar and contained herein should serve as a useful reference for the design of phosphorus removal facilities at sewage treatment plants.

PHOSPHORUS REMOVAL DESIGN SEMINAR

May 28 - 29, 1973

Skyline Hotel, Toronto

GENERAL SESSION - Monday morning ....Toronto/Vancouver Room

Members separate into Groups 1, 2 and 3 for sessions as follows:

		Group 1	Group 2	Group 3
		Toronto Rm.	Vancouver Rm.	London Rm.
1:30 to 4:30 pm	Day 1	Session "A"	Session "B"	Session "C"
9:00 to 12 noon	Day 2	Session "B"	Session "C"	Session "A"
12:15 pm - Lunch				
1:30 to 4:30 pm		Session "C"	Session "A"	Session "B"

PHOSPHORUS REMOVAL DESIGN SEMINAR

Chairman: Alex Redekopp, D.o.E.

Time	Detail	Speaker	Objectives
9:00 am	Welcome Address	Peter Higgins	To define seminar objectives and format, make miscellaneous announcements, and comment upon arrangements.
9:15 am	Introduction	Gordon VanFleet	Presentation of flow diagrams for alternative phosphorus removal schemes applicable to the Ontario scene, including CORA program.
9:35 am	Primary Treatment	Alan Wilkes	Phosphorus removal efficiencies related to chemical used, dose rate waste characteristics. Define ranges, removal of other constituents settling characteristics, etc.
10:00 am	C O F F E E		
10:30 am	Biological and Post-secondary Treatments	Jack Norman	For activated sludge and its variations. Phosphorus removal efficiencies related to chemical used, point of application, dose rate, waste characteristics, etc. Define ranges, other characteristics, etc.
11:00 am	Lagoon Treatment	Ron Hunsinger	Phosphorus removal characteristics related to chemical used, dose rate, waste characteristics, etc. Define ranges, removal of other constituents, settling characteristics, etc.
11:20 am	Presentations, questions and discussions		Opportunity for questions and individual short presentations from participants.
12:15 pm	L U N C H		

Session "A"

MECHANICAL and PROCESS DESIGN

Chairman: Paul Foley

Time	Topic	Speaker	Objective
40 min.	Chemical Added to Primary Tanks	Gerry Rupke Boris Boyko	Design criteria for sizing and equipment selection, specific problem areas, etc. for alternative chemicals.
40 min.	Chemical Added to Activated Sludge and its Variations, Lagoons, etc.	Boris Boyko Gerry Rupke	as above
20 min.	C o f f e e		
20 min.	Chemical Added to Secondary Effluent	Earl Shannon	Design criteria for sizing and equipment selection, specific problem areas, etc., for alternative chemicals.
20 min.	Miscellaneous Design	George Aldworth	Corrosion and encrustation, aeration equipment design.
40 min.	Presentations, Questions and Discussions		Limited number of presentations (5-minute maximum), questions and discussions.
	Adjourn.		

Session "B"

COSTS, INSTRUMENTATION and CHEMICAL HANDLING

Chairman: Charles Fisher

Time	Topic	Speaker	Objective
40 min.	Costs	George Powell Paul Crawford	Capital and operating costs for alternative systems, including equipment, chemical, labour and service costs. Interpretation of costs (financing available?)
40 min.	Instrumentation and Automatic Control	Stacy Daniels	Instrumentation available for automatic monitoring of process, control instrumentation and applicability of automatic control. (Potential benefits of automatic control.)
20 min.	C o f f e e		
40 min.	Chemical Handling	Terry Fahlenbock Brian LeClair	Availability of chemicals, their characteristics, costs, requirements for storage and feeding facilities. Potential problem areas.
40 min.	Presentations, Questions and Discussions		Limited number of presentations (5-minute maximum), questions and discussion.

Adjourn.

Session "C"

SLUDGE HANDLING, TREATMENT and DISPOSAL

Chairman: George Cornwall

Time	Topic	Speaker	Objective
25 min.	Sludge Characteristics	Ron Zaloum	Available knowledge on phosphorus rich sludges from alternative systems, concentrations, quantity.
35 min.	Sludge Thickening and Dewatering	Barry Hambley Ron Mondoux	Experience with gravity thickening, flotation, filtration, centrifugation, squeegee, etc., specific data - not theory pumping, piping.
20 min.	C o f f e e		
25 min.	Sludge Treatment	Roland Villiers	Heat treatment, digestion, incineration, liming. Design data, problem area.
35 min.	Sludge Disposal	Martin Wood	Experience or prediction with land fill, land spreading, disposal guidelines, problem areas.
40 min.	Presentations, Questions and Discussions		Limited number of presentations (5-minute maximum), questions and discussion.
	Adjourn.		

Table of Contents

PHOSPHORUS REMOVAL DESIGN SEMINAR

GENERAL SESSION

PHOSPHORUS REMOVAL IN ONTARIO

Prepared By

G. L. Van Fleet, P. Eng.

Phosphorus Programme Co-Ordinator

28 May, 1973

Ministry of the Environment
Sanitary Engineering Branch
135 St. Clair Avenue West
TORONTO M4V 1P5, Ontario

PHOSPHORUS REMOVAL IN ONTARIO

Phosphorus can be removed from wastewater in a number of different ways. The design of a new treatment works encompassing phosphorus removal could entail an entirely different approach than that used in integrating such treatment into an existing plant. The latter imposes constraints upon the designer and requires a more intimate knowledge of the individual plant processes.

Standard plant modifications or expansions can be conceived with a limited amount of information about the existing facilities. The consultant can fall back on a wealth of research and process development information to find satisfactory design parameters. Sufficient information has not been available to allow a similar approach in the provision of phosphorus removal.

It has, however, been shown that certain prime coagulants are compatible with physical settling and biological treatment systems, achieving substantial phosphorus removal efficiencies without significant impairment of existing processes. In some instances there are beneficial effects and in other cases the effects are not fully known. The designer must weigh the advantages and disadvantages on the basis of the limited information available today and judiciously integrate the chemical process into the existing wastewater treatment facility.

INTRODUCTION

By 1975, Ontario expects to have phosphorus removal facilities in operation at more than 200 wastewater treatment plants serving some 4.7 million persons (see Appendix I). This represents about 90% of the population serviced with sewers. Permanent phosphorus removal facilities must be operational in 75% of these plants by the end of 1973.

Existing waste treatment includes seasonal retention, continuous flow-through and aerated lagoons, trickling filters, oxidation ditches, primary and tertiary treatment plants, and various modifications of the activated sludge process. Plant capacities range from 0.04 to 180 MGD. In order to integrate chemical treatment into these processes has required a broad program of research.

The predictive methodology developed for selection of the most suitable prime coagulant for phosphorus removal at any particular waste treatment facility has been well documented in a recent paper by Boyko and Rupke (1). The selection of prime coagulant for the permanent facility must be based on a number of factors including:

- *delivered chemical cost*
- *projected operating cost*
- *anticipated capital expenditure*
- *ability of chemical to provide greater removal efficiencies if required at some later date*

- *effects on existing wastewater treatment processes*
- *utilization of existing facilities and physical effects of chemicals on those facilities*
- *effects on existing sludge treatment processes*
- *influence on existing sludge disposal practices.*

BACKGROUND

The International Joint Commission (IJC) Report (2) completed in 1969, following a six-year study of pollution in the lower Great Lakes drainage basin, recommended that phosphorus discharges from all sources in the lower Great Lakes be reduced to the lowest practical level. Subsequently, the Government of Canada, under terms of the Canada Water Act (1970), enacted a policy calling for a staged reduction in the phosphorus content of detergents to a limit *(by weight as P_2O_5)* of 20 percent by August 1970 and 5 percent by December 31, 1972. Concurrently, the Province of Ontario announced a policy requiring the installation of phosphorus removal facilities at municipal and institutional wastewater treatment plants located not only in the lower Great Lakes but also in the Ottawa River system, parts of the upper Great Lakes and throughout the inland recreational areas. Previous studies by the Ministry of the Environment (formerly the Ontario Water Resources Commission) on waters in the latter areas had shown phosphorus to be a major factor influencing eutrophication.

Initially, the policy required a minimum removal of 80% of the phosphorus from the wastewater plant influent with higher levels of removal to be

determined by further studies of the receiving waters. This criterion was subsequently superceded in the lower Great Lakes by the signing in April, 1972 of the Canada-United States International Agreement on Great Lakes Water Quality (3) which called for an effluent objective of 1 mg/l total phosphorus.

Permanent phosphorus removal facilities must be operational by December 31, 1973 in the most critically affected areas of the Province; by December 31, 1975 for those plants discharging to waters deemed to be in a less critical condition; and three years after notification in all other areas of the Province where problems are found to exist. The 1973 phase of the program will involve approximately 150 plants with capacities ranging from 0.04 to 24 MGD, serving an estimated 1,600,000 population. The 1975 phase will bring into operation another 50 plants ranging in size from 0.3 to 180 MGD, serving an additional 3,100,000 persons.

As a prelude to the Canada-United States Agreement, the Governments of Canada and Ontario, in August 1971, signed an agreement (4) to implement and accelerate programs of pollution control in the lower Great Lakes to meet the recommendations of the IJC. The agreement secured funding for a $250 million capital works program aimed at upgrading sewage collection systems and treatment works, including the installation of phosphorus removal equipment at an estimated cost of $15 million. An additional $6 million over the five year term of the agreement was provided for related research studies. Phosphorus removal technology and treatability studies were to be given top priority in the research

program. The \$6 million research fund is jointly shared and administered by the Governments of Canada and Ontario. While some of the research is being carried out by the experimental facilities of the two governments, many important projects are being funded through contract arrangements with the private sector.

TREATABILITY STUDIES

The program of integration of chemical treatment into existing plant processes involves the conducting of treatability studies (5) at each wastewater plant to determine the most effective chemical and point of application within the plant. The treatability studies are two-phase, involving in each plant an assessment of calcium, iron, and aluminum salts, with preliminary jar tests determining the most suitable chemical. Where necessary this is followed by a full-scale pilot study using the selected chemical. Essentially, the full-scale studies confirm the adaptability of the existing treatment facilities to the phosphorus removal process. Such studies are being carried out by Ontario Ministry of the Environment personnel, municipal staff and consulting engineers at a total estimated cost of \$2,200,000. Studies have been initiated or completed at virtually all existing mechanical wastewater treatment plants with December 31, 1973 compliance dates. The data obtained should be used by the consultant to design the permanent equipment. In the event that the new facilities cannot be operational by the required target date, it will be necessary to bring into operation the temporary equipment utilized during the full-scale pilot studies.

Studies to date have demonstrated that an effluent level of 1 mg/l of total phosphorus is technically feasible with the addition of chemicals to either primary or secondary treatment facilities. Chemical treatment has been similarly effective in achieving 80% removal of the phosphorus entering the wastewater treatment plant except in cases of extremely low raw sewage total phosphorus concentrations. Chemical treatment cannot be expected to continuously produce an effluent below 0.5 mg/l total phosphorus. The effectiveness of phosphorus removal is dependant upon the amount and type of chemical used and, of course, the characteristics of the waste stream.

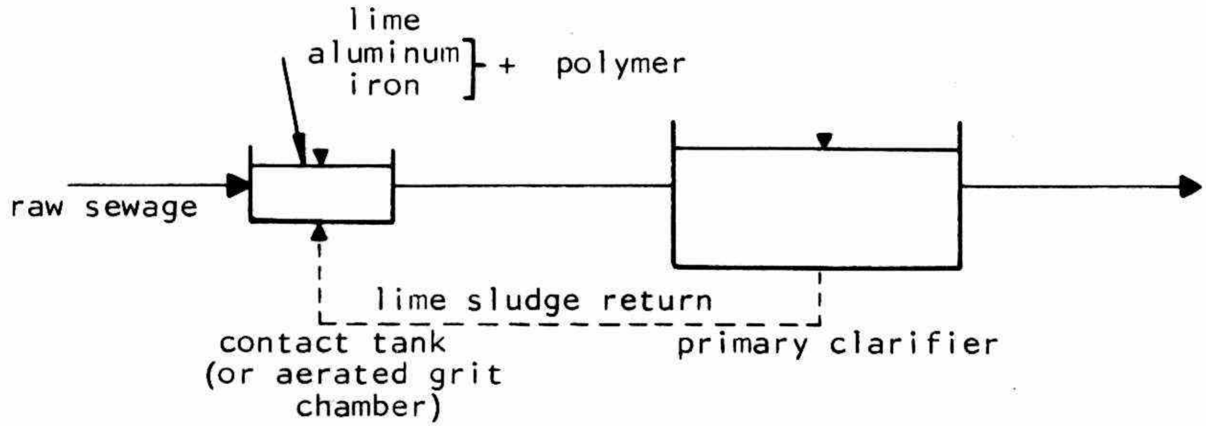
Chemical Application Alternatives

The alternatives for chemical treatment in Ontario, at the present time, include the use of aluminum, iron and calcium salts. Until recently, most studies involved the specific use of alum, ferric chloride and lime. Alternate points for chemical addition are shown in Figure I (6). It can be seen that all three salts can be applied to the raw sewage with the phosphate precipitate being removed with the sludge from the primary clarifier. Satisfactory mixing can frequently be achieved when the chemical is added to the suction side of the raw sewage pumps or into an aerated grit chamber.

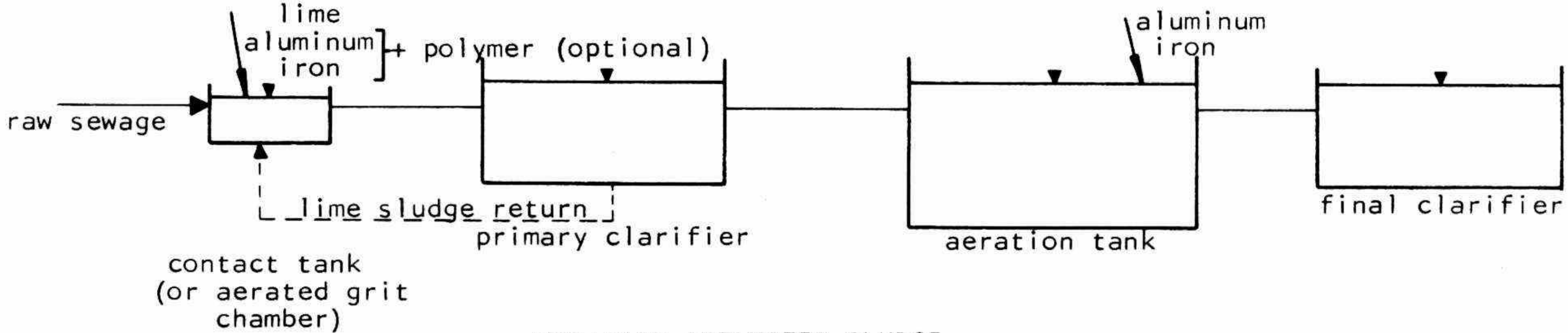
Because of the high pH requirement, lime is excluded from use in the biological treatment system. Aluminum or iron salts can be fed directly into the aeration tank or immediately following the aeration tank provided a point of sufficiently turbulent flow can be found for mixing. Polymers are optional and have not been found significantly effective except

CHEMICAL ADDITION POINTS

PRIMARY PLANT



CONVENTIONAL ACTIVATED SLUDGE



MODIFIED ACTIVATED SLUDGE

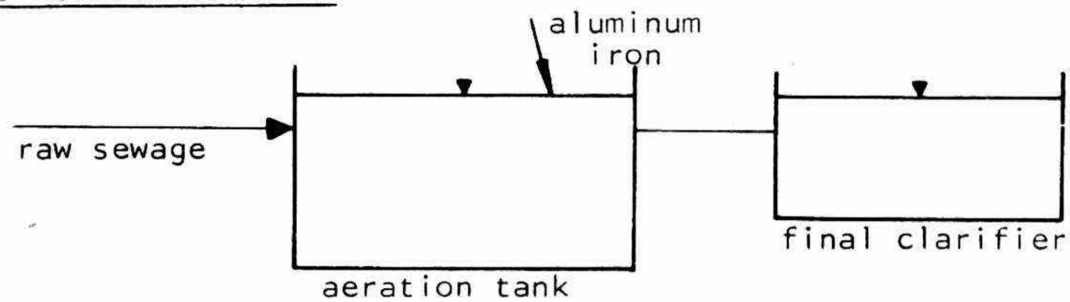


FIGURE 1

in conditions where the clarifiers are hydraulically overloaded. For a plant containing both primary and biological treatment units jar testing studies would be carried out on both the raw sewage and the final effluent to determine the most economical point of chemical addition. Tertiary units could have chemical addition directly ahead of them and would have jar test studies carried out on the secondary effluent. Studies have shown that chemicals applied to the final secondary effluent produce dosage results similar to those obtained when the chemicals are added to the mixed liquor.

RESEARCH STUDIES

Through funding under the Canada/Ontario Agreement, research programs on phosphorus removal have been expanded and intensified to explore concepts put forward by municipalities, universities, industries and consulting firms. In addition, long-term full-scale and laboratory studies have been initiated by both Environment Canada and the Ontario Ministry of the Environment to refine the technology of phosphorus removal. In some cases, the treatability and research studies have been integrated. The longer term research studies provide an opportunity to assess specific process phenomenon, including sludge treatment and disposal, under the influence of varying quantities and types of prime coagulants.

The sludges produced are being used for laboratory and field investigations into various aspects of sludge utilization and disposal. These studies would determine the maximum rates of sludge application which can be used on agricultural soils without polluting ground and surface

water or reducing the quantity and quality of the crops produced. Secondly, the behaviour of chemical sludges in soils is being studied to determine the effects of the sludges on the physical, chemical and biological properties of the soils.

Also under study are a number of potentially useful prime coagulants which may reduce the cost of phosphorus removal. Projects have been carried out at Dunnville and Chatham on the use of waste pickle liquor from steel product manufacturing operations. Initial studies indicate that the use of this problem waste will be helpful in achieving required phosphorus controls at a considerable saving to the municipalities.

A spray irrigation and spray runoff study, irrigating lands with and without crop cover, is being carried out at Smithville to assess the effectiveness of this process to remove organics and phosphorus. For small municipalities this may be a clear alternative to chemical treatment. The project, involving irrigation of a wheat crop, was begun in 1972. The evaluation of runoff from a nearby uncropped plot indicated 60 to 70% reduction of phosphorus with little effect on the receiving stream.

The Province has a large number of lagoons, some of which operate on a continuous discharge basis with others having discharges confined to spring and fall periods. Successful studies have been carried out on both types of facilities using alum, ferric chloride and lime.

Full-scale studies using the three prime coagulants have been run for extended periods at various sized plants employing a variety of sewage and sludge treatment processes. A report on these investigations has been published (1).

Many other important investigations are currently in progress or have only recently been completed. These include investigations of the settling behaviour of physical-chemical flocs, variations in effluent quality, factors influencing chemical addition rates and many other studies which will provide a greater insight into phosphorus removal phenomenon.

CONCLUSIONS

The integration of chemical treatment into existing wastewater treatment plants in Ontario has necessitated the development of a research methodology capable of providing in a very short time period sufficient design information to successfully implement the Province's phosphorus removal program. This methodology has involved both treatability studies and intensive research investigations. The treatability studies are proceeding at all wastewater treatment plants requiring phosphorus removal and it is expected that the resultant data will contribute to the design of the most efficient and economical chemical process for each particular plant within the required timing. Research and demonstration projects carried out under contract by the private sector and by personnel of the Ontario Ministry of the Environment and

Environment Canada have made it possible to confidently design permanent facilities to meet the required percent phosphorus removal or effluent quality criteria. Continuing investigations will produce more accurate information on sludge handling and disposal and will improve upon existing wastewater treatment technology which will undoubtedly result in more efficient operation and a lowering of costs.

May 28, 1973

APPENDIX I

INDEX OF MUNICIPALITIES REQUIRING PHOSPHORUS REMOVAL

A list of municipalities, the level of phosphorus removal to be achieved at each, and the compliance dates for permanent operation are attached. It should be noted that this list includes not only existing facilities, but also those proposed to be built over the next few years. In some cases the construction completion date will be later than the compliance date. Obviously, in such cases, phosphorus removal will come on-stream when the new wastewater treatment plant becomes operational.

Where the designation "Future" is used it means that phosphorus removal is not required at the wastewater treatment plant at the present time. Therefore no compliance date or level of removal is shown. Should water quality studies at these location indicate the need for phosphorus removal the municipalities will be so notified and have three years to bring permanent facilities into operation.

This list should not be considered as final and is subject to expansion or change to meet evolving program requirements.

May 28, 1973

INDEX OF MUNICIPALITIES REQUIRING PHOSPHORUS REMOVAL

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Acton (Town)	1 mg/l	1975
Ajax (Town)	1 mg/l	1975
Alexandria (Town)	-	Future
Alfred (Village)	-	Future
Alliston (Town)	-	Future
Almonte (Town)	-	Future
Amherstburg (Town)	1 mg/l	1973
Anson, Hindon & Minden (Twp.)	1 mg/l	1973
Armstrong (Twp.)	-	Future
Arnprior (Town)	80%	1975
Arthur (Village)	1 mg/l	1973
Assiginack (Twp.)	-	Future
Atikokan (Twp.)	-	Future
Aurora (Town)	80%	1973
Aylmer (Town)	1 mg/l	1973
(Ontario Police College)	1 mg/l	1973
- B -		
Bala (Muskoka Lakes Twp.)	80%	1973
Balfour (Twp.)	-	Future
Balmertown (Imp. District)	-	Future
Bancroft (Village)	-	Future
Barrie (City)	80%	1973
Barry's Bay (Village)	80%	1973
Bath (Village)	-	Future
Beardmore (Imp. District)	-	Future
Beaverton (Village)	80%	1973
Beeton (Village)	-	Future
Belle River (Town)	1 mg/l	1973
Belleville (City)	1 mg/l	1975
Belmont (Village)	1 mg/l	1973
Bicroft (Imp. District)	1 mg/l	1973
Black River-Matheson (Twp.)	-	Future
Blenheim (Town)	1 mg/l	1973
Blenheim (Twp.) - Plattsville	1 mg/l	1973
Bobcaygeon (Village)	1 mg/l	1973
Bolton (Village)	1 mg/l	1975
Bothwell (Town)	1 mg/l	1973
Bowmanville (Town)	1 mg/l	1975
Bracebridge (Town)	80%	1973
Bradford (Town)	80%	1973
Brantford (City)	1 mg/l	1973
Brighton (Village)	-	Future

May 28, 1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Brighton (Twp.) - Warkworth Inst.	1 mg/l	1973
Brockville (City)	1 mg/l	1975
Bruce Mines (Town)	-	Future
Bucke (Twp.)	-	Future
Burk's Falls (Village)	-	Future
Burlington (Town)	1 mg/l	1975
- C -		
Caldwell (Twp.)		
P.V. of Verner	80%	1973
Caledonia (Town)	1 mg/l	1973
Calvert (Twp.)	-	Future
Campbellford (Town)	1 mg/l	1973
Cannington (Village)	80%	1973
Capreol (Town)	-	Future
Cardiff (Bicroft Imp. District)	80%	1973
Cardinal (Village)	-	Future
Carleton Place (Town)	80%	1975
Casselman (Village)	-	Future
Cavan (Twp.)		
Ontario Correctional Institute	1 mg/l	1973
Cayuga (Village)	1 mg/l	1973
Chalk River (Village)	-	Future
Chapleau (Twp.)	-	Future
Chatham (City)	1 mg/l	1973
Chesley (Town)	-	Future
Chesterville (Village)	-	Future
Clinton (Town)	-	Future
Cobalt (Town)	-	Future
Cobden (Village)	80%	1973
Cobourg (Town)	1 mg/l	1975
Cochrane (Town)	-	Future
Colborne (Village)	-	Future
Coldwater (Village)	-	Future
Collingwood (Town)	80%	1973
Coniston (Town)	-	Future
Copper Cliff (Town)	-	Future
Cornwall (City)	1 mg/l	1975
Cornwall (Twp.)	-	Future
Courtright (Village)	1 mg/l	1973
Cumberland (Twp.)	-	Future

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Deep River (Town)	-	Future
Delhi (Town)	1 mg/1	1973
Deloro (Village)	-	Future
Desoronto (Town)	-	Future
Drayton (Village)	1 mg/1	1973
Dresden (Town)	1 mg/1	1973
Dryden (Town)	-	Future
Dumfries South (Twp.)		
P.V. of St. George	1 mg/1	1973
Dundalk (Village)	1 mg/1	1973
Dundas (Town)	1 mg/1	1975
Dunnville (Town)	1 mg/1	1973
Durham (Town)	-	Future
Dutton (Village)	1 mg/1	1973
Dysart et al Haliburton (Twp.)	1 mg/1	1973

- E -

Ear Falls (Imp. District)	-	Future
Eganville (Village)	-	Future
Elizabethtown (Twp.)	-	Future
Elliot Lake (Twp.)	-	Future
Elmira (Town)	1 mg/1	1973
Elmvale (Village)	-	Future
Elora (Village)	1 mg/1	1973
Emo (Twp.)	-	Future
Englehart (Town)	-	Future
Enniskillen (Twp.) - Oil City	1 mg/1	1973
Eramosa (Twp.)	1 mg/1	1973
Erin (Village)	-	Future
Ernestown (Twp.)		
Amherstview	-	Future
Odessa	-	Future
Espanola (Town)	-	Future
Essex (Town)	1 mg/1	1973
Exeter (Town)	-	Future

- F -

Fauquier (Twp.)	-	Future
Fenelon Falls (Village)	1 mg/1	1973
Fergus (Town)	1 mg/1	1973
Ferris East (Twp.)	-	Future
Flesherton (Village)	-	Future
Forest (Town)	-	Future
Fort Erie (Town)		
Crystal Beach	1 mg/1	1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Fort Erie (Town)	1 mg/l	1975
Fort Frances (Town)	-	Future
Frankford (Village)	1 mg/l	1973
- G -		
Galt (City)	1 mg/l	1973
Gananoque (Separated Town)	-	Future
Georgetown (Town)	1 mg/l	1975
Georgian Bay (Twp.)		
MacTier	80%	1973
Georgina (Twp.)		
Sutton	80%	1973
Geraldton (Town)	-	Future
Glencoe (Village)	1 mg/l	1973
Goderich (Town)	-	Future
Gosfield, North (Twp.) - P.V. Cottam	1 mg/l	1973
Gosfield, South (Twp.)		
Cedar Beach	1 mg/l	1973
Grand Valley (Village)	1 mg/l	1973
Gravenhurst (Town)	80%	1973
Gravenhurst (Town) - Ontario Hosp.	80%	1973
Grimsby (Town)		
Grimsby Beach	-	Future
West End Lagoon	-	Future
Main Plant	-	Future
Guelph (City)	1 mg/l	1973
- H -		
Hagersville (Village)	1 mg/l	1973
Haileybury (Town)	-	Future
Hamilton (City)	1 mg/l	1975
Hanover (Town)	-	Future
Harriston (Town)	-	Future
Harrow (Town)	1 mg/l	1973
Hastings (Village)	1 mg/l	1973
Havelock (Village)	1 mg/l	1973
Hawkesbury (Town)	80%	1975
Hearst (Town)	-	Future
Hespeler (Town)	1 mg/l	1973
Himsworth, North (Twp.)		
Callander	80%	1973
Huntsville (Town)	80%	1973

May 28, 1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Ignace (Twp.)	-	Future
Ingersoll (Separated Town)	1 mg/l	1973
Iroquois (Village)	-	Future
	- J -	
Jarvis (Village)	1 mg/l	1973
Joyceville (Institution)	1 mg/l	1973
	- K -	
Kapuskasing (Town)	-	Future
Keewatin (Town)	-	Future
Kemptville (Town)	80%	1973
Kenora (Town)	-	Future
Killaloe Station (Village)	80%	1973
Kincardine (Town)	-	Future
Kingston (City)	1 mg/l	1975
Kingston (Twp.)	1 mg/l	1975
Kingsville (Town)	1 mg/l	1973
Kitchener (City)	1 mg/l	1973
	- L -	
Lakefield (Village)	1 mg/l	1973
Lancaster (Village)	-	Future
Larder Lake (Twp.)	-	Future
Latchford (Town)	-	Future
Leamington (Town)	1 mg/l	1973
Leeds & Lansdowne, Front of (Twp.)	-	Future
Levack (Town)	-	Future
Lincoln (Town) - Beamsville	-	Future
Lindsay (Town)	1 mg/l	1973
Listowel (Town)	80%	1973
Little Current (Town)	-	Future
Lively (Town)	-	Future
London (City)		
Adelaide, Greenway, Oxford, Pottersburg and Vauxhall	1 mg/l	1973
Longlac (Twp.)	-	Future
L'Orignal (Village)	-	Future
Loughborough (Twp.)		
Sydenham	1 mg/l	1973
Lucan (Village)	-	Future

May 28, 1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Macdonald, Meredith & Aberdeen Additonal (Twp.)	-	Future
MacTier (Georgian Bay Twp.)	80%	1973
Madoc (Village)	1 mg/l	1973
Manitouwadge (Imp. District)	-	Future
Marathon (Twp.)	-	Future
Markdale (Village)	-	Future
Markham (Town) - John Street, Old Plant & Unionville	1 mg/l	1975
Marlborough (Twp.) - Rideau Industrial Farm	80%	1973
Marmora (Village)	1 mg/l	1973
Massey (Town)	-	Future
Mattawa (Town)	-	Future
Meaford (Town)	-	Future
Merrickville (Village)	80%	1973
Michipicoten (Twp.)		
Wawa	-	Future
Midland (Town)	80%	1973
Mildmay (Village)	-	Future
Millbrook (Village)	1 mg/l	1973
Milton (Town)	1 mg/l	1975
Milverton (Village)	-	Future
Mississauga (Town)	1 mg/l	1975
Mitchell (Town)	1 mg/l	1973
Moore (Twp.)		
P.V. of Corunna	1 mg/l	1973
P.V. of Brigden	1 mg/l	1973
Morrisburg (Village)	-	Future
Mount Forest (Town)	80%	1973
Muskoka Lakes (Twp.)		
Bala	80%	1973
Port Carling	80%	1973
- N -		
Napanee (Town)	1 mg/l	1975
Neelon & Garson (Twp.)	-	Future
Nepean (Twp.)	80%	1975
Neustadt (Village)	-	Future
Newburgh (Village)	-	Future
Newcastle (Village)	-	Future
New Hamburg (Town)	1 mg/l	1973
New Liskeard (Town)	-	Future
Newmarket (Town)	80%	1973
Niagara Falls (City)	1 mg/l	1975

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Niagara-on-the-Lake (Town)	-	Future
Nipigon (Twp.)	-	Future
North Bay (City)	80%	1973
Norwich (Village)	1 mg/l	1973
Norwood (Village)	1 mg/l	1973
- O -		
Oakville (Town)		
Trafalgar & East End and Navy Street	1 mg/l	1975
Oil Springs (Village)	1 mg/l	1973
Oliver (Twp.)	-	Future
Omemee (Village)	1 mg/l	1973
Onaping (Imp. District)	-	Future
Orangeville (Town)	1 mg/l	1975
Orillia (City)	80%	1973
Oshawa (City)	1 mg/l	1975
Osnabruck (Twp.)	-	Future
Ottawa (City)	80%	1975
Ottawa (City)		
Uplands Canadian Forces Base	80%	1973
Owen Sound (City)	80%	1973
- P -		
Paisley (Village)	-	Future
Palmerston (Town)	-	Future
Paris (Town)	1 mg/l	1973
Parry Sound (Town)	80%	1973
Pembroke (Town)	80%	1975
Penetanguishene (Town)	80%	1973
Penetanguishene (Town)		
Ontario Hospital	80%	1973
Perth (Town)	80%	1973
Petawawa (Village) and Canadian Forces Base	1 mg/l	1975
Peterborough (City)	1 mg/l	1973
Petrolia (Town)	1 mg/l	1973
Pickering (Village)	-	Future
Pickering (Twp.)	1 mg/l	1975
Picton (Town)	1 mg/l	1975
Plantangenet (Village)	-	Future
Playfair (Twp.)		
Ramore	-	Future
Point Edward (Village)	1 mg/l	1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Port Carling (Muskoka Lakes Twp.)	80%	1973
Port Colborne (City)	1 mg/l	1975
Port Dover (Town)	1 mg/l	1973
Port Elgin (Town)	-	Future
Port Hope (Town)	1 mg/l	1975
Port McNicoll (Village)	80%	1973
Port Perry (Village)	1 mg/l	1973
Port Rowan (Village)	1 mg/l	1973
Port Stanley (Village)	1 mg/l	1973
Powassan (Town)	80%	1973
Prescott (Separated Town)	1 mg/l	1975
Preston (Town)	1 mg/l	1973
- R -		
Rainy River (Town)	-	Future
Raleigh (Twp.)		
Ontario Hospital	1 mg/l	1973
Raleigh & Tilbury East (Twps.)		
P.V. of Merlin	1 mg/l	1973
Rayside (Twp.)		
Azilda	-	Future
Red Lake (Twp.)	-	Future
Renfrew (Town)	80%	1975
Richmond (Village)	80%	1973
Richmond Hill (Town)	1 mg/l	1975
Ridgetown (Town)	1 mg/l	1973
Rockland (Town)	-	Future
Rodney (Village)	1 mg/l	1973
- S -		
St. Catharines (City)	1 mg/l	1975
St. Isidore de Prescott (Village)	-	Future
St. Marys (Separated Town)	1 mg/l	1973
St. Thomas (City)	1 mg/l	1973
Sarnia (City)	1 mg/l	1973
Sarnia (Twp.)		
Bright's Grove	-	Future
Sault Ste. Marie (City)	-	Future
Schreiber (Twp.)	-	Future
Seaforth (Town)	-	Future
Shackleton & Machin (Twp.)		
Fauquier	-	Future
Shelburne (Village)	-	Future
Sherborne, McClintock and Livingstone (Twp.)		
Dorset Forestry School	1 mg/l	1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Sidney (Twp.)		
Batawa	1 mg/l	1973
Simcoe (Town)	1 mg/l	1973
Sioux Lookout (Town)	-	Future
Smiths Falls (Separated Town)	80%	1973
Smithville (West Lincoln Twp.)	-	Future
Smooth Rock Falls (Town)	-	Future
Sombra (Twp.)		
P.V. of Sombra	1 mg/l	1973
P.V. of Port Lambton	1 mg/l	1973
Southampton (Town)	-	Future
South River (Village)	-	Future
Stayner (Town)	-	Future
Stirling (Village)	1 mg/l	1973
Stouffville (Whitchurch-Stouffville Town)	1 mg/l	1975
Stratford (City)	1 mg/l	1973
Strathroy (Town)	1 mg/l	1973
Sturgeon Falls (Town)	80%	1973
Sudbury (City)	-	Future
Sundridge (Village)	80%	1973
Sutton (Georgina Twp.)	80%	1973
	- T -	
Tavistock (Village)	1 mg/l	1973
Teck (Twp.)		
Kirkland Lake	-	Future
Terrace Bay (Twp.)	-	Future
Thamesville (Village)	1 mg/l	1973
Thessalon (Town)	-	Future
Thornbury (Town)	-	Future
Thunder Bay (City)		
Port Arthur & Fort William	-	Future
Tilbury (Town)	1 mg/l	1973
Tilbury East & Raleigh (Twps.)		
P.V. of Merlin	1 mg/l	1973
Tilbury North (Twp.)		
P.V. of Stoney Point	1 mg/l	1973
Lighthouse Shores	1 mg/l	1973
Tilbury West (Twp.)		
P.V. of Comber	1 mg/l	1973
Tillsonburg (Town)	1 mg/l	1973
Timmins (Town)	-	Future
Tisdale (Twp.)	-	Future

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Metropolitan Toronto		
Humber, Long Branch, Main, North Toronto & Scarborough	1 mg/l	1975
Tottenham (Village)	-	Future
Trenton (Separated Town)	1 mg/l	1975
Trenton (Separated Town)		
Canadian Forces Base	1 mg/l	1975
Tweed (Village)	1 mg/l	1973
	- U -	
Uxbridge (Town)	80%	1973
	- V -	
Valley East (Twp.)	-	Future
Vankleek Hill (Town)	-	Future
Vaughan (Town)		
West Don	1 mg/l	1975
Kleinburg	-	Future
	- W -	
Walkerton (Town)	-	Future
Wallaceburg (Town)	1 mg/l	1973
Waterdown (Village)	-	Future
Waterford (Town)	1 mg/l	1973
Waterloo (City)	1 mg/l	1973
Watford (Village)	1 mg/l	1973
Webbwood (Town)	-	Future
Welland (City)	1 mg/l	1975
Wellesley (Village)	1 mg/l	1973
Wellington (Village)	-	Future
West Lincoln (Twp.)		
Smithville	-	Future
West Lorne (Village)	1 mg/l	1973
Westminster (Twp.)	1 mg/l	1973
Westport (Village)	80%	1973
Wheatley (Village)	1 mg/l	1973
Whitby (Town)		
Corbett Creek	1 mg/l	1975
Municipal	1 mg/l	1975
Ontario Hospital	-	Future
Whitchurch-Stouffville (Town)		
Stouffville	1 mg/l	1975
Whitney (Twp.)	-	Future

May 28, 1973

MUNICIPALITY	PHOSPHORUS REMOVAL REQUIREMENT	COMPLIANCE DATE (Dec. 31)
Wiarton (Town)	-	Future
Wilmot (Twp.)		
P.V. of Baden	1 mg/l	1973
Winchester (Village)	-	Future
Windsor (City)		
Little River and Westerly	1 mg/l	1973
Wingham (Town)	-	Future
Woodstock (City)	1 mg/l	1973
Woolwich (Twp.)		
P.V. of St.Jacobs	1 mg/l	1973

- Z -

Zurich (Village)	-	Future

REFERENCES

(1) Boyko, B.I. and Rupke, J.W.G., Technical Implementation of Ontario's Phosphorus Removal Program, Purdue Industrial Waste Conference, May, 1973.

(2) International Joint Commission - Canada and United States, "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River", Vol. 1, Summary (1969).

(3) Canada-United States International Agreement on Great Lakes Water Quality (April, 1972).

(4) Canada-Ontario Agreement on the lower Great Lakes (August, 1971).

(5) "Guidelines for Conducting Ttreatability Studies for Phosphorus Removal at Wastewater Treatment Plants", Ministry of the Environment, Sanitary Engineering Branch, April, 1972.

(6) Mills, G.H., Nutrient Control Program for Ontario, Canadian Institute on Pollution Control, April 15, 1971.

GUIDELINES FOR CONDUCTING TREATABILITY STUDIES FOR PHOSPHORUS REMOVAL AT WASTEWATER TREATMENT PLANTS

An information brief for consulting engineers and municipal officials and a supplement to Guidelines for Initiating Treatability studies. Further information can be obtained by contacting Mr. J.W.G. Rupke or Mr. G. L. Van Fleet.

Ministry of the Environment
135 St. Clair Avenue West
Suite 400
TORONTO, Ontario
M4V 1P5

April 28, 1972

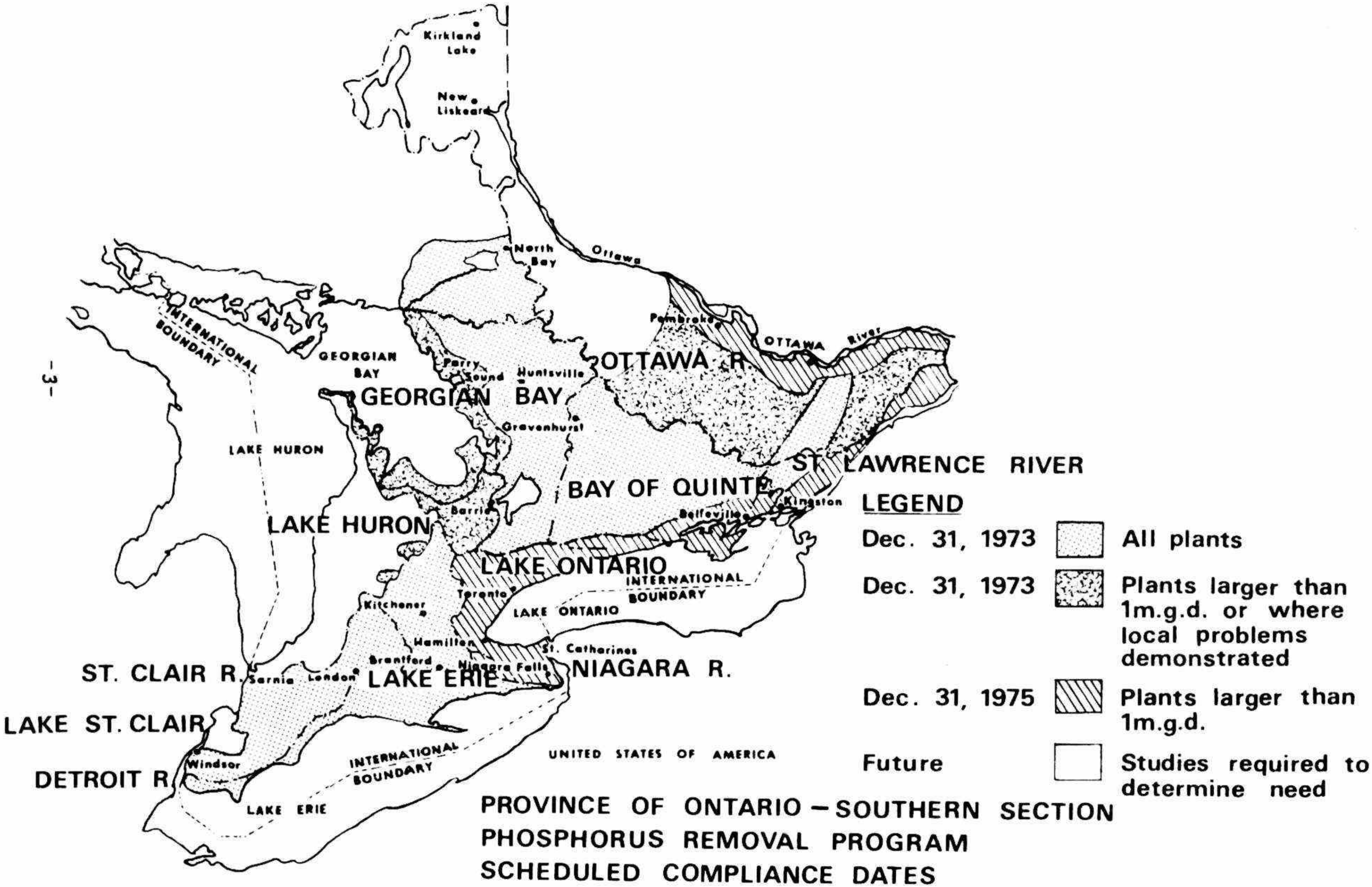
GUIDELINES FOR CONDUCTING TREATABILITY STUDIES FOR PHOSPHORUS REMOVAL AT WASTEWATER TREATMENT PLANTS

INTRODUCTION

Nutrients are known to play a significant role in the growth and proliferation of algae in the aquatic environment. The control of specific nutrient inputs, such as phosphorus, can aid in correcting existing eutrophication problems and protect our waterways from over-abundant algal production.

The Province of Ontario is presently involved in a five-year program to control, by 1975, phosphorus discharges from more than two hundred existing wastewater treatment plants serving some 4.7 million persons. Permanent phosphorus removal facilities must be operational by December 31, 1973, in the most critically affected areas of the Province; by December 31, 1975, for those discharging to waters deemed to be in a less critical condition; and three years after notification in all other areas of the Province where problems are found to exist or where protective measures are required. Figure I outlines the areas of the Province affected by the program and the respective compliance dates. The program is a response to International Joint Commission recommendations on the lower Great Lakes and the demonstrated need for nutrient controls in prime recreational waters throughout the Province.

Figure 1



PROVINCE OF ONTARIO – SOUTHERN SECTION
PHOSPHORUS REMOVAL PROGRAM
SCHEDULED COMPLIANCE DATES

Affected wastewater treatment plants located in the Upper Great Lakes and Ottawa River Systems are required to remove 80 per cent of the phosphorus from sewage which enters the treatment plant. An average effluent total phosphorus concentration of 1 mg/l is required at all affected plants which discharge directly or indirectly to the St. Clair River, Lake St. Clair, the Detroit River, Lake Erie, the Niagara River, Lake Ontario and the Ontario section of the St. Lawrence River. The permanent facilities and prime chemical coagulant selected must, in each case, be capable of greater removal efficiencies, as further receiving water studies may dictate the need for more stringent requirements.

GUIDELINE OBJECTIVES

These guidelines are designed to assist personnel involved in carrying out phosphorus removal treatability studies in determining the most efficient and economical means to implement phosphorus removal through chemical addition at existing wastewater treatment plants. The methodology, which includes both jar testing and pilot study phases, would allow the prediction of the prime coagulant best suited for phosphorus removal at any particular treatment facility and a determination of whether the chemical used would have any effect on the existing wastewater treatment process, facilities, method of sludge treatment, and subsequent sludge disposal practices. The choice of chemical would be limited to the process most compatible with sewage characteristics and the existing facilities, taking into account the physical layout of the plant and the delivered cost and availability of the particular chemical. As it has been established that raw sewage characteristics vary from

municipality to municipality, the need for a treatability study at each plant is evident. In some cases it may be sufficient to accurately predict the most suitable chemical for a particular plant on the basis of jar testing studies alone.

PROCEDURES

Initial work consists of preliminary jar tests to establish the prime precipitant (iron, aluminium, or calcium salts) that will consistently provide the degree of phosphorus removal required. The jar testing should cover the equivalent of three one-week periods of intensive testing using each of the chemicals throughout the day and in the various days of the week. Analyses should be conducted on raw samples and the supernatants from the jars. Through the use of probability plots, comparative chemical dosages and costs can be obtained. This information in conjunction with an assessment of the visual and analytic data obtained during the study and a knowledge of the existing plant facilities can provide a base for predicting the most suitable chemical.

An interim study report should be prepared and submitted based on the jar tests and include sufficient data to substantiate the conclusions reached. This report may also include a recommendation for a full-scale pilot study using the most efficient chemical. Such a recommendation should be contingent upon a site evaluation to determine if existing facilities can be readily used for phosphorus removal in the manner which is proposed.

When the interim study report is reviewed and approved, a full-scale pilot study may be carried out. The study can frequently be run on a portion of the plant and produce results equivalent to the complete plant at substantial savings. Prior to commencing the full-scale study, the various points of chemical application should be assessed to ensure that adequate mixing capability is present in the existing plant. Mixing may be obtained through chemical discharge into the suction side of pumps, in an aerated grit chamber, into interconnecting channels or into the aeration tank. In most cases it will not be necessary to utilize flash mixers.

If full-scale tests are to be conducted, it is expected that the studies would be of approximately six weeks duration for a primary treatment plant. For a secondary treatment plant, eight weeks of full-scale operation should yield the required information. Following completion of the full-scale studies, a complete treatability study report is to be prepared, documenting problems encountered at the plant, confirming the chemical to be used in permanent operation and containing recommendations for the implementation of phosphorus removal.

Phase I - Jar Testing

The use of jar testing procedures to simulate water treatment plant conditions is a well known and often used technique (1). More recently this same jar test procedure has been used to provide preliminary design

(1) Simplified Procedures for Water Examination. AWWA Manual, M12, p. 42.

information on phosphorus removal by chemical precipitation in municipal wastewater treatment systems. Tests are carried out on grab samples of either the raw sewage or final effluent (see Appendices A and B). For primary plants, varying dosages of aluminum salts, iron salts and lime are added to raw sewage samples. Tests on biological treatment units are carried out using aluminum and iron salts applied to the final effluent which produces results similar to those obtained from chemical application to the mixed liquor. When primary and biological units are in operation both of the aforementioned tests are carried out.

The procedure, which parallels that used by the potable water treatment plant operators (1), is described as follows:

1. *Adopt a jar test procedure which must be continued throughout the test programme at the plant. Use a standard arbitrary timing sequence ensuring adequate mixing and reaction time, [e.g. 5 minute fast mix (100 rpm) followed by 15 minute slow mix (25 rpm), settle for 30 minutes and sample supernatant].*

2. *Take a 7 litre grab sample of the waste stream to be tested.*

3. *Retain a well mixed 1 litre raw sample of the above for measurement of total phosphorus and pH. Occasionally check soluble phosphorus, suspended solids and BOD (see step 8).*

4. *Fill six one litre beakers and place them under the multiple stirring apparatus.*

5. *Dose beakers 2-6 with varying dosages of the chemical selected, covering the initial ranges listed in Table I. Beaker no. 1 is a control and receives no chemical.*

Table I

Chemical		Dosage Ranges (mg/l)
Common Name	Chemical Formula	
Alum	$Al_2(SO_4)_3 \cdot 14H_2O$	75 - 300
Ferric Chloride	$FeCl_3$	5 - 30*
Lime	$Ca(OH)_2$	75 - 300
*as Fe^{+++}		

Add the selected chemical dosages to each beaker in succession while running the mixer at 100 rpm. It is important that the chemicals be added as rapidly as possible. Continue to operate at this high speed after the last chemical addition to provide the required fast mixing time.

6. *Adjust the mixer speed to slow mix in accordance with the procedure adopted in step 1. and allow to run for the required slow mixing time.*

7. *During the slow mix and subsequent settling period record the following visual observations (a sample laboratory data sheet and instructions are attached as Appendix C):*

- *a comment on the time required for flocculation to take place. (slow, fast, etc.)*
- *floc size after flocculation time. (small, medium, large)*
- *floc settling characteristics. (slow to fast)*
- *supernatant quality. (turbid to clear)*
- *volume of sludge produced.*

8. *Analyze the well mixed raw sample and each of the jar supernatants, including the control sample, for total phosphorus and pH. Occasionally check soluble phosphorus, suspended solids and BOD on samples; generally each of these additional analyses should not exceed 10 per cent of the number of total phosphorus analyses carried out.*

9. *Repeat steps 2. to 8. ignoring Table I, using fresh samples of wastewater to narrow down the range of chemical dosages used. The rationale for choosing subsequent dosages involves attempting to bracket the range of removal efficiency or effluent quality required by selecting one dosage lower than the objective, one near the objective and one higher than the objective. (i.e. if the initial tests using alum, ferric chloride and lime showed phosphorus removals as listed in Table II, the indicated changes would be made in subsequent tests) At the present time the objective is either 80 per cent removal or 1 mg/l effluent total phosphorus depending upon the particular drainage basin basin into which the plant discharges. This has been discussed previously.*

Table II

Chemical	Dosage (mg/l)	Total P Removal (%)	Total P in Jar Supernatant (mg/l)	Dosages to be used in Subsequent Tests (mg/l)
Alum	100	45	2.5	
	150	70	1.5	150
	200	85	1.0	200
	250	95	0.8	250
	300	98	0.8	
Ferric Chloride	5*	78	1.3	4*
	10*	89	1.0	7*
	15*	95	0.8	10*
	20*	97	0.8	
	25*	98	0.8	
Lime	100	30	3.5	
	150	65	1.7	
	200	73	1.4	200
	250	84	1.1	250
	300	87	1.0	300
* As Fe^{+++}				

It is essential that the jar tests be carried out over an extended period of time, preferably of three weeks duration, in order that a wide and representative variety of sewage characteristics are encountered. Grab samples should be taken at different times of the day and on various days of the week. Once the range of chemical dosages has been established, do not alter these dosages unless the results show that you are consistently under-dosing or overdosing. In order to have sufficient data to draw meaningful conclusions, it is essential that a minimum of 10 data points are obtained at each chemical dosage on each waste stream being studied. Typical jar testing runs to obtain the necessary data points using low, middle and high chemical dosages are shown in Appendices A and B.

Statistical plots of the data obtained are used to determine the relative chemical dosages. Although in full-scale operation the effectiveness of phosphorus removal is determined on the basis of average plant operating results, for purposes of evaluating jar test data, comparable chemical dosages are obtained at the 80 per cent confidence level on probability curves. Sample probability curves are attached as Appendix D. It should be noted that each curve represents a single chemical dosage into a particular waste stream. Separate graphs would be used for each chemical on each waste stream. The data presented in Appendix D is for illustrative purposes only and should not be taken to suggest that there is a standard correlation between per cent removal and effluent total phosphorus level.

Data Analyses

Rather than looking at the average total phosphorus removal for each set of data, more meaningful information can be gained by plotting each set of 10 points on arithmetic probability paper. This can be done by arranging the data in numerical order of percentage total phosphorus removal from raw sample or supernatant (effluent) total phosphorus concentration. Then plot % total P removal or effluent total P concentration on the ordinate versus $\frac{x}{n+1}$ on the abscissa

where n = total number of samples
x = sample number, e.g. 1, 2, 3, 4, etc.

When all data are thus plotted a direct comparison can be drawn between the various chemical dosages used. Use a separate graph for plotting the various removal results for each chemical on a particular waste stream.

Two significant aspects of these curves should be considered.

1. *The relative vertical position of the plot lines indicates the degree of effectiveness of the precipitant used at that given dosage.*

2. *The slope of the plot line indicates the degree of certainty or reliability of the chemical in achieving the required results.*

From this analytical data, the relative economics of the various chemical processes for phosphorus removal can be determined on the basis of optimum dosage, delivered cost, and availability of the chemicals.

These data should form part of the interim study report to be completed prior to initiating full-scale studies.

<u>Phase II - Full-scale Pilot Studies</u>

The results of the preliminary jar tests conducted as Phase I of the treatability studies for phosphorus removal will yield a conclusion as to the optimum chemical to be used for phosphorus removal at the particular wastewater treatment plant. Full-scale studies can then be conducted using this prime coagulant to yield information in the following areas:

- *confirm the chemical dosage*
- *optimize the point of application*
- *prove the suitability of plant hydraulics*

- *prove that existing mechanical equipment will operate satisfactorily under the new service conditions*
- *provide data on sludge characteristics*
- *indicate the actual final effluent quality that will be attained*
- *provide total annual operating costs related to phosphorus removal.*

In some special cases, full-scale studies may not be required or even warranted. Previous experience, accumulated technical information, and plant mechanical and process status could all combine to make full-scale studies unnecessary.

If full-scale tests are to be conducted, it is expected that the studies would be of approximately six weeks duration for a primary treatment plant. For a secondary wastewater treatment plant, eight weeks of full-scale operation should yield the required information. Such a study would only involve chemical addition into the waste stream indicated most promising by the jar tests, assuming that addition at this point yielded satisfactory results. Subsequent work in altering the point of application to reduce chemical dosage can be conducted after the full-scale facility is on stream permanently.

An assessment of digester operation during these studies is not considered essential. Flexibility in design of permanent facilities is obviously required.

Under certain circumstances an extended study beyond the time periods previously outlined may be required. The presence of a significant

industrial waste load, e.g. cannery wastes, could necessitate more extensive studies both in the jar testing and full-scale pilot work.

The prime objective of the full-scale temporary phosphorus removal studies is to demonstrate the feasibility of effecting phosphorus removal at a particular installation without necessitating extensive plant modifications or additions. Some of the mechanical plant aspects that may be affected by phosphorus removal are:

- *raw sludge collection and handling capability*
- *return sludge pumping capacity*
- *digester heat exchange capacity.*

Essentially the full-scale studies should demonstrate that phosphorus removal, using the prime coagulant indicated by the jar tests, is compatible with the existing wastewater treatment processes. While effecting phosphorus removal is the prime objective, the study should not be carried out in a manner which might lead to a deterioration in plant effluent quality.

In order to assess plant performance during the study period, an appreciable sampling and analytical work load will result. Under routine conditions it is expected that composite sampling of liquid sewage streams will be conducted a maximum of three times per week. These samples would be analyzed for total phosphorus, soluble phosphorus, BOD, pH, and suspended solids. Grab samples of various sludge streams will be taken several times a week. Expenditures eligible for reimbursement

are only those covering analytical work conducted in addition to normal plant operational analyses.

During a secondary treatment plant study, it is expected that approximately 130 man-hours of laboratory services would be required to handle the necessary analyses; for a primary plant, the manpower requirements for laboratory analyses are estimated at 90 man-hours.

The normal in-plant monitoring required for plant operation should be sufficient to yield the necessary information on the effects of implementing phosphorus removal at the existing wastewater treatment plant. However, if normal in-plant tests are minimal, it is suggested that the following observations be conducted during the study: sludge levels in clarifiers, dissolved oxygen concentrations in aeration tanks, sludge volume index values, and return sludge rates.

A previous outline entitled, "Guidelines for Initiating Treatability Studies for Phosphorus Removal" contained applications and instructions for rebate of treatability study costs. It was pointed out that treatability study equipment purchased specifically for such a study would revert to the Crown if reimbursement for such material was made. In this regard, it is advisable for the operating authority to directly purchase such items as chemical storage tanks and feed pumps suitably sized for use in the permanent facilities; such equipment could then be incorporated into the permanent treatment facility as part of the regular capital costs. Where lime is selected as the prime coagulant

the Ministry will provide, on loan, a package lime feed system for the duration of the full-scale study. Although the use of temporary "swimming pool" type storage tanks is an expedient measure, they have proven unreliable, resulting in uncontrolled spills and the loss of large volumes of chemical.

The manpower costs, exclusive of analytical work, associated with the full-scale studies will arise from three major areas:

- *initial plant inspection and equipment set-up.*
- *technical support for the duration of the study.*
- *sampling and on-site analyses conducted during the study.*

During these studies, technical assistance is available, if required, from the Ministry of the Environment, Research Branch. Having conducted many full-scale phosphorus removal studies, staff can provide information both during initial plant set-up and in assessing operating problems that may occur during the study. In any case, if operating problems are encountered during a phosphorus removal study, it is essential that the Phosphorus Programme Co-Ordinator be made aware of the nature of these difficulties. Such contact should ensure that proper operating conditions are being effected during these studies.

The final treatability study report should document the full-scale studies and contain appropriate recommendations to implement phosphorus

removal on a permanent basis without deterioration in existing plant processes. The report must include total annual operating cost estimates for phosphorus removal and the appropriate cost breakdown.

Contributions from the Research, Project Operations and Sanitary Engineering Branches are gratefully acknowledged.

APPENDIX A

PHOSPHORUS REMOVAL PROGRAM — JAR TESTING PROCEDURES

SAMPLE RUN Nº							
1.	S_1	C_1	A_L	A_M	A_H	F_L	F_H
2.	S_2	C_2	F_L	F_M	F_H	L_L	L_H
3.	S_3	C_3	L_L	L_M	L_H	A_L	A_H
4.	S_4	C_4	F_L	F_M	F_H	L_L	L_M
5.	S_5	C_5	L_L	L_M	L_H	A_L	A_M
6.	S_6	C_6	A_L	A_M	A_H	F_L	F_M
7.	S_7	C_7	L_L	L_M	L_H	A_M	A_H
8.	S_8	C_8	A_L	A_M	A_H	F_M	F_H
9.	S_9	C_9	F_L	F_M	F_H	L_M	L_H
10.	S_{10}	C_{10}	L_L	L_M	L_H	F_L	F_H
11.	S_{11}	C_{11}	F_L	F_M	F_H	A_L	A_H
12.	S_{12}	C_{12}	A_L	A_M	A_H	L_L	L_H
13.	S_{13}	C_{13}	F_L	F_M	F_H	A_L	A_M
14.	S_{14}	C_{14}	A_L	A_M	A_H	L_L	L_M
15.	S_{15}	C_{15}	L_L	L_M	L_H	F_L	F_M
16.	S_{16}	C_{16}	A_L	A_M	A_H	L_M	L_H
17.	S_{17}	C_{17}	L_L	L_M	L_H	F_M	F_H
18.	S_{18}	C_{18}	F_L	F_M	F_H	A_M	A_H

Note: This series would be used in assessing raw sewage at a plant where there are primary clarifiers.

This is a typical series of jar testing runs considering all three chemicals with low, middle and high dosages of each chemical. Note that this series utilizes 18 different grab samples of the waste stream and produces 10 results for each chemical dosage. This number will take into account variations in the waste stream and provide minimum data for statistical plots.

The symbols designate the following:

S = waste stream sample with no chemical added (for immediate analyses of unsettled sample)
C = control sample with no chemical added (for analyses on supernatant after jar test)
A_L = low alum dosage
A_M = middle alum dosage
A_H = high alum dosage
F_L = low ferric chloride dosage
F_M = middle ferric chloride dosage
F_H = high ferric chloride dosage
L_L = low lime dosage
L_M = middle lime dosage
L_H = high lime dosage

APPENDIX B

PHOSPHORUS REMOVAL PROGRAM – JAR TESTING PROCEDURES

SAMPLE RUN Nº							
1.	S_1	C_1	A_L	A_M	A_H	F_L	F_H
2.	S_2	C_2	F_L	F_M	F_H	A_L	A_H
3.	S_3	C_3	A_L	A_M	A_H	F_M	F_H
4.	S_4	C_4	F_L	F_M	F_H	A_M	A_H
5.	S_5	C_5	A_L	A_M	A_H	F_L	F_M
6.	S_6	C_6	F_L	F_M	F_H	A_L	A_M
7.	S_7	C_7	A_L	A_M	A_H	F_L	F_H
8.	S_8	C_8	F_L	F_M	F_H	A_L	A_H
9.	S_9	C_9	A_L	A_M	A_H	F_M	F_H
10.	S_{10}	C_{10}	F_L	F_M	F_H	A_M	A_H
11.	S_{11}	C_{11}	A_L	A_M	A_H	F_L	F_M
12.	S_{12}	C_{12}	F_L	F_M	F_H	A_L	A_M

Note: This series would be used in assessing

a) unchlorinated final effluent at all biological treatment plants;

b) raw sewage at plants where there are no primary clarifiers;

c) raw sewage at aerated and conventional waste stabilization ponds (continuous discharge facilities).

This is a typical series of jar testing runs considering only alum and ferric chloride with low, middle and high dosages of each chemical. This series utilizes 12 different grab samples of the waste stream and produces 10 results for each chemical dosage. This number will take into account variations in the waste stream and provide minimum data for statistical plots.

S = waste stream sample with no chemical added (for immediate analyses of unsettled sample)

C = control sample with no chemical added (for analyses of supernatant after jar test)

A_L = low alum dosage

A_M = middle alum dosage

A_H = high alum dosage

F_L = low ferric chloride dosage

F_M = middle ferric chloride dosage

F_H = high ferric chloride dosage

APPENDIX C

INSTRUCTIONS FOR USING THE LABORATORY DATA SHEETS

The primary purpose of this form is to provide a worksheet for both the jar tests and the subsequent phosphorus analyses. It can also be used for reporting the results of the jar tests.

Concentrations of the stock solutions used should be recorded (e.g. Alum 50 gm/l). Note that 1 gm per litre = 1 mg per ml so that calculation of the amount of stock chemical to be used for a given dosage is minimal. For instance, using alum at 50 gm/l, for a dosage of 150 mg/l would be 150/50 = 3 ml per litre of sewage.

Mixing times will normally be the standard 100 rpm rapid mix for 5 minutes, 20 - 30 rpm slow mix for 15 minutes and 30 minute settling time. There may arise in the future, the need to change these times, therefore a record must be kept to distinguish the two sets of results. Provision has been made on the form to record the time each of these jar testing stages was started if no interval timer is available.

JAR TESTS

The first three rows, "CHEMICAL(S) USED". "DOSAGE". and "ml of chemicals used" can be filled in prior to the start of the jar tests. The line "ml of chemicals used" is provided so that the volumes of chemical required can be determined and noted prior to commencement of the jar test.

The time of appearance of a floc after start of the slow mix (flocculation) stage will be helpful in plants where flocculation facilities are limited.

The floc size should be recorded after the mixer is stopped (i.e., at commencement of the half hour settling period). Since no physical measurement of floc size will be taken, the terms are somewhat subjective and relative. The sizes, however, should be described in standard terms -

ie: very large - the floc being large masses

large -

medium -

small -

no floc - a condition that might be found in tests on final effluent.

Settling rates will also be described in relative terms -

ie: Very rapid	-	all floc collects immediately on the bottom of the beaker when the mixer is stopped
Rapid	-	floc settles within several minutes of the mixer being stopped
Medium	-	floc take no more than 10 minutes to settle
Slow	-	requires most of settling time
Nil	-	no discernable settling

Turbidity will be described in relative terms; the effect of colour, if any, should be disregarded. The terms used should be -

ie: Very turbid - difficult (or impossible) to see through beaker under normal room light

Turbid - large shapes discernable through beaker

Hazy -

Slightly Hazy -newspaper can be read through beaker

Clear - like drinking water

The colour of the supernatant liquid should be recorded, not the colour of the sludge.

pH measurements since they take little time, should be done on all six beakers. It will be necessary to record the temperature of only one of the beakers.

Soluble phosphorus analyses should be performed on-site to eliminate the possibility of post-precipitation.

Reduction in concentration of soluble phosphorus is based on the soluble phosphorus content of the control;

$$\text{i.e., \% reduction} = \frac{\text{control-dosed sample}}{\text{control}} \times 100\%$$

Reduction of total phosphorus is based on the original sample;

$$\text{i.e, \% reduction} = \frac{\text{original-dosed sample}}{\text{original}} \times 100\%$$

Provision has been made on the form to record suspended solids and BOD. Only a few of these need to be done (i.e., one or two for each chemical dosage on each waste stream being assessed).

LABORATORY DATA SHEET
JAR TESTS - PHOSPHORUS REMOVAL

PLANT .... DATE SAMPLED ....

SAMPLE DESCRIPTION .... TIME SAMPLED ....

REAGENTS USED CONCENTRATION

.... gm/l RAPID MIX at .... rpm for .... minutes. Time started ....

.... gm/l SLOW MIX at .... rpm for .... minutes. Time started ....

.... gm/l SETTLING before analysis for ...... minutes. Time started ....

	RUN NUMBER	S	C	2nd JAR	3rd JAR	4th JAR	5th JAR	6th JAR
JAR TEST	CHEMICAL(s) USED (in order of addition for 2 or more)	ORIGINAL SAMPLE	CONTROL					
	DOSAGE in mg/l							
	ml of chemical used							
	APPEARANCE of FLOC (minutes after start of slow mix)							
	Floc size after slow mix							
	Settling rate							
	Turbidity							
	Colour							
	pH							
	Temperature							

SOLUBLE PHOSPHORUS	Volume of sample used							
	Diluted to							
	Absorbance (spectrophotometer reading)							
	mg/l P (from graph)							
	mg/l P in sample							
	% reduction							

TOTAL PHOSPHORUS	Volume of sample digested							
	Diluted to							
	Volume of above used							
	Diluted to							
	Absorbance (spectrophotometer reading)							
	mg/l P (from graph)							
	mg/l P in sample							
	% reduction							

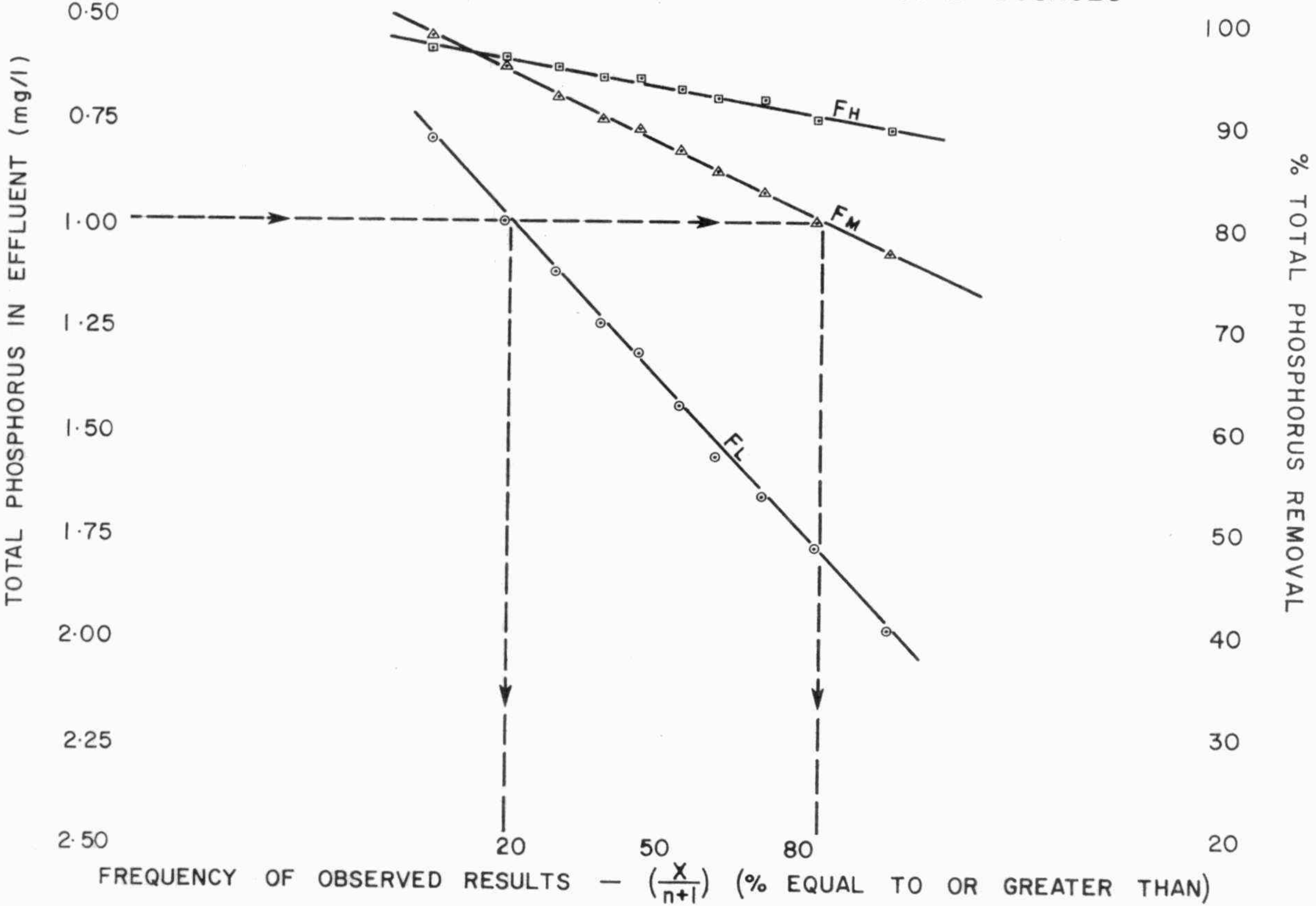
OTHER ANALYSES	Suspended solids - mg/l							
	Volatile suspended solids - %							
	BOD							

REMARKS:

FORM 11-002

APPENDIX D

PROBABILITY CURVES FOR VARIOUS CHEMICAL DOSAGES



PHOSPHORUS REMOVAL
BY CHEMICAL ADDITION
USING PRIMARY TREATMENT

ALAN WILKES,
JAMES F. MACLAREN LIMITED

MAY 1973

PHOSPHORUS REMOVAL BY CHEMICAL ADDITION USING PRIMARY TREATMENT

1. INTRODUCTION

Phosphorus removal by chemical addition ahead of primary clarification has been studied extensively in North America and has been shown to be a viable technique for controlling phosphorus discharges at sewage treatment plants.

For the purposes of this presentation, primary treatment for phosphorus removal will be defined in terms of the point of addition of chemical, i.e. upstream of the primary clarifiers. Thus, this discussion, while making reference to phosphorus removal at primary plants will not be limited to that type of treatment plant.

Phosphorus removal may be considered to be a transfer of both suspended and soluble forms of phosphorus originally present in raw sewage from that sewage to the sludges formed in the primary clarifiers. This transfer is effected by chemical addition which precipitates soluble phosphorus, coagulates suspended solids and incorporates the phosphorus-rich solids into the primary sludge. The primary effluent flowing from the clarifier is thus relatively low in phosphorus.

2. TYPES OF PHOSPHORUS COMPOUNDS PRESENT IN SEWAGE

When adding chemical to raw sewage for the purpose of phosphorus removal we are dealing with the forms of phosphorus as they originally enter the plant and we have little or no control at present over the types and quantities appearing. It is appropriate at this point therefore to review the major types of phosphorus compounds appearing in raw sewage.

The total phosphorus content of incoming sewage is in the order of 7 to 10 mg/l expressed as phosphorus,based on daily composite samples. In nutrient removal studies, in addition to considering total phosphorus values, attention is also paid to one major species of soluble phosphorus, i.e. ortho-phosphorus compounds. It should be pointed out that the ortho-phosphates are not the only soluble phosphate compounds present, as will be discussed later.

2.1 Ortho-Phosphates

Four species of ortho-phosphates may exist in equilibrium with each other, the distribution of concentrations of the species being dependent upon the pH value of the solution or sewage under consideration.

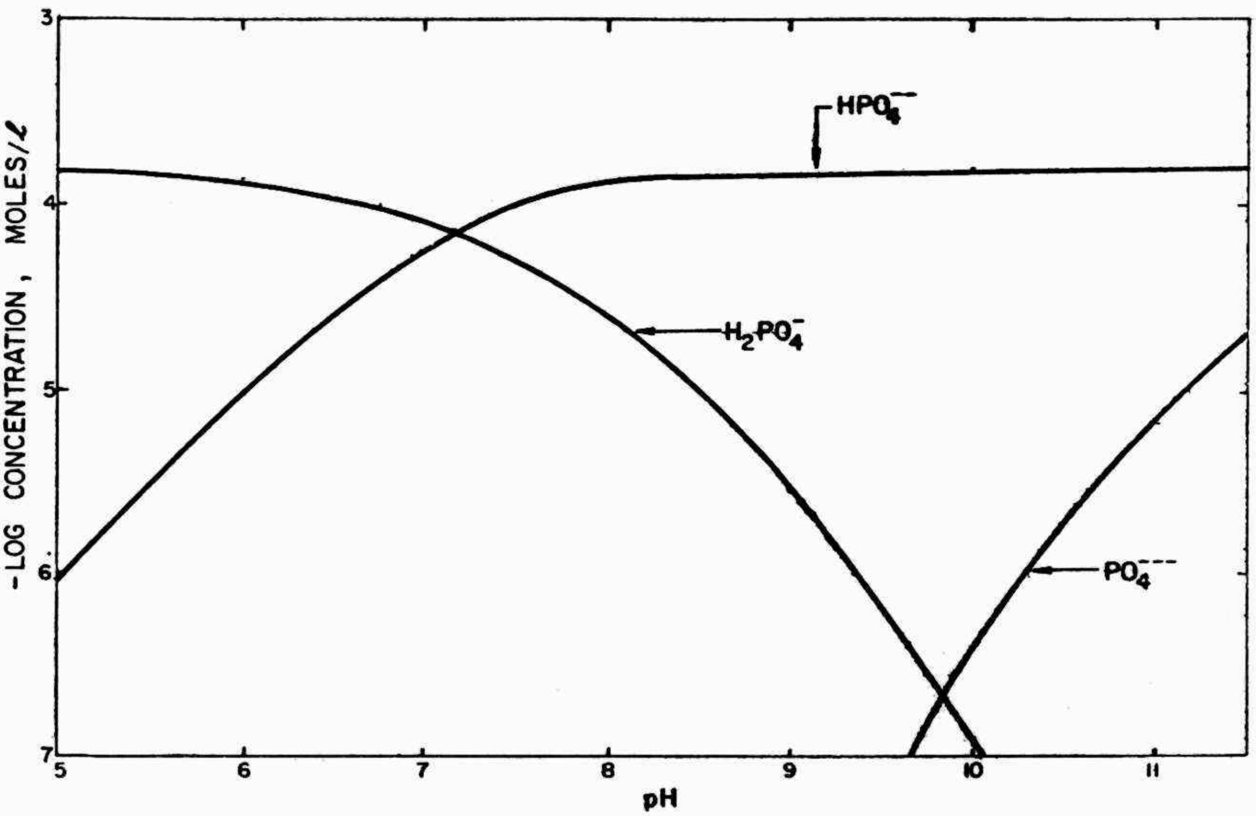
Figure 1 shows the type of distribution that occurs; for simplicity, other soluble phosphates, e.g. pyro- and tri-polyphosphates, have been omitted.

In the highly acid range (i.e. pH of 2.2 and less) which is beyond the range of this Figure, phosphoric acid, H_3PO_4 is predominant.

In the pH range 2.2 to 7.2, still on the acid side, substantial concentrations of dihydrogen phosphate ion, $H_2PO_4^-$ appears. This is a monovalent ion.

As the pH value increases to the alkaline side, the divalent ion, mono-hydrogen phosphate predominates. The formula for this ion is HPO_4^{--}

As the pH approaches 12, the trivalent ion PO_4^{---}, the phos-



EQUILIBRIUM DISTRIBUTION OF DISSOLVED PHOSPHATE IONS

FIG. 1

phate ion, appears in significant concentrations.

2.2 Polyphosphates

These are also present in raw sewage. Examples of these are:

a) Ring type compounds, such as sodium trimetaphosphate, $Na_3(PO_3)_3$

b) Chain compounds such as sodium polymetaphosphate, $(Na\ PO_3)_N$

c) Sodium pyrophosphate $Na_4P_2O_7$

d) Sodium tripolyphosphate $Na_5P_3O_{10}$

These polyphosphates hydrolize slowly to form ortho-phosphates of the type previously discussed. This hydrolysis occurs to some extent in the aeration sections of an activated sludge plant, causing an increase in ortho phosphate levels as the sewage passes through a secondary treatment plant.

2.3 Organic Phosphates

Amongst the organic phosphates which occur are esters, anhydrides and phosphagens.

3. MECHANISM OF PHOSPHORUS REMOVAL

3.1 Introduction

Chemical addition to raw sewage effects phosphorus removal by chemical or physical/chemical mechanisms only. This is in contrast to phosphorus removal by chemical dosing at the outlet of aeration tanks where biological removal has taken place to some extent, prior to chemical addition.

The mechanisms involved in removal of phosphorus from sewage streams are: precipitation and adsorption of various phosphate species, flocculation of suspended solids, including newly formed phosphorus precipitates, followed by settling of solids to yield a supernatant of low phosphorus content.

3.2 Precipitation of Phosphorus Compounds

With alum and ferric chloride it is generally assumed that the trivalent cations react with the trivalent phosphate ion to form the compounds $AlPO_4$ or $FePO_4$. It should be noted, however, that the chemistry of phosphates is somewhat more complex and this really represents an over-simplification of the situation.

Organic and polyphosphate compounds are also removed by a combination of more complex precipitation reactions, and adsorption onto floc particles.

The mechanism associated with phosphorus removal by lime addition is different from the mechanism of alum and ferric chloride precipitations.

The formation of insoluble phosphorus compounds with lime is a pH dependent reaction. As the pH is raised, a compound known as calcium hydroxyapatite is precipitated. This has a variable composition but it is generally regarded to be of the form $Ca_5OH(PO_4)_3$.

A review of the literature reveals various estimates for the pH required to effect phosphorus removal by lime addition. A minimum value of 9 has been recommended and values of 11 and higher have been cited.

Referring to Ministry of the Environment studies at the Newmarket Water Pollution Control Centre, it was reported in May 1972 that during this study the average pH of the primary effluent was 9.6 providing orthophosphate reductions from 6.7 in the raw sewage to 1.2 in the primary effluent.

Referring back to precipitation with alum and ferric chloride now that the influence of pH on phosphate precipitation has been introduced, it has been reported that precipitation with these metal salts is pH dependent, although not to the extent of the lime process. The minimum solubility of aluminum phosphate occurs at pH 6 giving an optimum range of pH for precipitation of 5.5 - 6.5. Optimum precipitation with ferric salts occurs at pH 4.5 - 5.0.

It is unlikely that either of these ranges will obtain in common waste waters as a general rule, and satisfactory removal of phosphorus can, of course, be achieved at higher pH levels near neutrality, as demonstrated by current treatability studies.

3.3 Competing Chemical Reactions

An essential difference between waste treatment by chemical addition and a process used in the chemical process industries for the production of a specific product is that the latter usually operates with reasonably pure reactants of uniform or predictable quality. This provides for good process control, and products of predictable composition and quantity.

Sewage as a reactant is neither simple, uniform nor predictable in its composition, and contains numerous constituents in varying quantities, over which one has no control. It is not surprising, therefore, that when treating a waste water chemically, for the removal of phosphorus, in addition to

the desired reaction (i.e. removal of phosphorus),side reaction originating from constituents other than phosphorus occur.

3.3.1 Alum and Ferric Chloride

Considering first alum and ferric chloride treatment, these chemicals react with bicarbonate alkalinity producing either aluminum or ferric hydroxide, whilst evolving carbon dioxide.

Thus, with alum:

$$Al_2(SO_4)_3 \cdot 14\ H_2O + 6HCO_3^- \longrightarrow 2\ Al(OH)_3 + 6CO_2 + 14\ H_2O + 3SO_4^{2-}$$

Although it would appear that such side reactions detract from the effectiveness of phosphorus removal by consuming excess chemical, it is pointed out that the hydroxides are gelatinous in nature and their presence aids in solids capture, floc formation and settling of the solids from the sewage. In this respect, therefore, they enhance the second mechanism upon which effective phosphorus removal is dependent, i.e., the separation of the phosphorus-rich solids from the waste.

In addition, freshly precipitated aluminum and ferric hydroxides have the ability to take up phosphate anions from waste water, which further contributes to the overall phosphorus removal process.

The simplified precipitation model involving aluminum or ferric phosphate formation would require one mole of cation per mole of phosphorus to be precipitated. The competing reactions serve to increase the chemical demand of waste water over and above what is theoretically required for phosphorus precipitation.

Work has been done to determine the ratio of cation dose to phosphorus content of the waste required to achieve a given degree of phosphorus removal.

Alum manufacturers have published data from research studies indicating that most practical applications require aluminum ion to phosphorus ratios of 1.5:1 to 2.0:1 for adequate removals, as compared to the stochiometric requirement of 0.87:1. In view of the variability of waste composition from plant to plant and the complex nature of phosphate chemistry,such ratios should be regarded as empirical, to be established for each treatment plant under consideration.

3.3.2 Lime

When removing phosphorus by lime treatment at least two other reactions may occur between the lime and waste water constituents:

a) the removal of calcium bicarbonate hardness to precipitate calcium carbonate according to the equation:
$Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2\ CaCO_3 + 2\ H_2O$

b) the reaction of lime with carbon dioxide present in the waste water to precipitate calcium carbonate, according to the equation:
$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$

The result of these two reactions is the formation of calcium carbonate precipitates. These reactions increase the lime demand for elevation of pH. Benefits from the formation of calcium carbonate, however, are as follows:

a) the calcium carbonate acts as a weighting agent in the primary sludges, providing better settling

and solids consolidation.

b) adsorption of polyphosphate anions on to the calcium carbonate enhances overall phosphorus removal.

3.4 Flocculation of Solids After Precipitation

Ideally speaking, to gain maximum benefit from chemical addition for phosphorus removal, the precipitated phosphorus compounds, together with suspended solids originally present in the influent sewage should be flocculated by a period of gentle agitation of the chemically treated waste. The following processes would then occur:

a) formation of large flocs with better settling characteristics;
b) capture and incorporation into the flocs of fine particles not readily settled in normal plant operation;
c) adsorption of various phosphate compounds onto floc surfaces.

Flocculation may be achieved either by the inorganic chemicals already added for phosphorus removal, or by the addition of organic flocculating agents or polymers.

The former mechanisms have been discussed under the section on "Competing Chemical Reactions".

Flocculation by organic polymers is an effective supplement to phosphorus removal by chemical addition, particularly at primary plants. These flocculants have the following characteristics.

a) they are long chain, high molecular weight organic polymers (e.g. polyacrylamides);

b) they possess positive, negative or zero electrical charge. (Cationic, anionic and non-ionic polymers, respectively).

When used for coagulation of sewage they have been found effective in concentrations up to 0.5 ppm: some polymers operate satisfactorily at lower concentrations.

The flocculants effect agglomeration of suspended solids through a combination of the following mechanisms:

a) neutralization of the electrical repulsive forces surrounding the suspended particles. (The need for bench scale testing to determine a suitable polymer is thus obvious.)
b) adsorption of the long chain polymers onto the particle surfaces, followed by bridging between adjacent particles by the polymer chains. This mechanism leads to floc formation. These flocs, if moved gently around the bulk of the waste, then contribute further to clarification by capturing fine particles in suspension.

4. PRACTICAL CONSIDERATIONS AND EXPERIENCE

4.1 Introduction

For the precipitation/flocculation process, literature indicates that rapid mixing of waste and chemical, followed by a reaction time of at least five minutes should be provided for effective precipitation. A further period of 5 to 20 minutes of gentle agitation is then required to properly flocculate the sewage. The flocculated waste should then be delivered with a minimum of turbulence into the primary clarifiers, to minimize floc break-up.

The foregoing is an idealized process. Generally speaking, we have not been in a position to rebuild inlet works of plants to comply with these ideal requirements.

In keeping with the Government's policy to implement the nutrient removal programme at all plants in the affected area at a minimum cost, it is necessary to utilize that portion of the plant's exisitng inlet works which appears suitable for contact of chemical and sewage.

4.2 Point of Addition of Chemical

It is obvious that an area of high turbulence is required. This may be provided by the following:

a) aerated grit tanks
b) preaeration tanks
c) Parshall flumes
d) comminutors
e) raw sewage lift pumps

The particular addition points chosen are probably as numerous as the plants studied. However, to illustrate what is possible the following examples are mentioned:

Studies with ferric chloride at the Sarnia Primary Treatment Plant indicated that precipitant added anywhere along the preaeration tanks provided adequate phosphorus removal.

The City of Windsor, when studying phosphorus removal at the West Windsor Primary Treatment Plant, tried three points of addition; namely, the channel prior to the grit removal tank, the inlet channel to the raw well from which the sewage is pumped to the grit removal tanks, and finally, chemical was injected directly into the suction of the

sewage pumps lifting the waste from the wet well to the grit removal tanks. It was concluded that the most efficient phosphorus removal was achieved when the chemical was added on the suction side of the raw sewage pumps.

At the City of St. Thomas Secondary Sewage Treatment Plant, chemical was added to the sewage immediately upstream of the coarse screens and mixed in the aerated grit tank. Phosphorus removal across the plant as a whole was highly effective and orthophosphate analyses on raw sewage flowing from the grit chamber to the primary clarifiers indicated highly effective precipitation of orthophosphate compounds.

This discussion of points of addition of chemicals leads quite naturally into what, from an engineering point of view, may be regarded as an advantage of phosphorus removal by primary treatment.

Quite often as sewage plants undergo various phases of expansion, the aeration and settling tanks assume locations which may be scattered over a relatively large area within the plant boundaries. Phosphorus removal by chemical addition to the outlet of the aeration tanks would thus necessitate several points of addition, one for each subsection of the plant.

To complicate matters, there are instances where the flows through particular parts of the plant are not monitored by instrumentation. The provision of pacing signals for control loops which are individual to each aeration section would necessitate installing new instrumentation.

In such plant, however, the raw sewage normally flows through a common inlet works and further, either the total influent flow or the total effluent flow is measured. In this instance

therefore, the implementation of phosphorus removal by primary treatment would be facilitated for two reasons:

a) a single point of addition somewhere in the common inlet works is available, rather than multiple points of addition at each aeration section, as would be the case with secondary treatment, and
b) the chemical flow may be controlled by an output signal originating from the influent or effluent plant flow instrumentation, normally present.

The foregoing is not to be interpreted to mean that in fragmented plants, primary treatment should be considered in all cases. Indeed, it has been our experience that in at least one major plant the total influent sewage flow is arrived at by summing the flows through each of five aeration sections, each one being supplied with either Parshall flume or magnetic flow measurement.

These comments are offered as food for thought during the contemplation of design of chemical addition equipment.

4.3 Methods of Chemical Addition

Lime is normally added as a 20-25% slurry into the area of high turbulence. Package units with capability for lime storage, slurry preparation and metering are now available.

There are several variations which have been tried when adding ferric chloride or alum to the raw sewage flows. The simplest method of addition is direct injection of the undiluted liquid into the sewage flow. Alternatively, if it is considered that the configuration of the inlet works does not provide adequate dispersal and mixing time, it is possible to provide dilution of the chemical with water prior to its

introduction into the sewage flow to effect more efficient distribution of chemical in the waste.

It is also possible to install a launder, say, across the width of a channel, the launder being equipped with 'V' notches or down-spouts to ensure good distribution of chemicals across the width of the channel.

When the "as delivered" chemical (50% solution for alum, 40% for ferric chloride) is diluted prior to injection into the sewage stream, it is suggested that the use of effluent for dilution be avoided. The impurities in the effluent may react with the chemical precipitant prematurely, thus leaving less of the active constituents available for phosphorus removal from the sewage flows.

4.4 Chemical Dosages Used

The following ranges of dosages may be considered representative of primary treatment requirements:

Lime	150 - 300 ppm	as	$Ca(OH)_2$
Ferric salts	15 - 35 ppm	as	Fe^{3+}
Alum	75 - 250 ppm	as	aluminum sulphate

4.5 Settling Considerations - Removal of B.O.D. and Suspended Solids

Primary effluent quality will be dependent upon incoming B.O.D. and suspended solids load to the plant, for a given clarifier hydraulic loading and chemical addition rate.

At hydraulic loadings of 500 gals/ft^2/day, suspended solids and B.O.D. levels in primary effluent of 55 - 65 mg/l may be expected.

Effluents from primary clarifiers designed at loading rates of 1000 gals/ft.^{2}/day may contain up to 100 mg/l of each constituent.

Ministry of the Environment research studies have concluded that conventional clarifier loadings should be used for alum and ferric flocs, whereas lime flocs may be settled at higher hydraulic loadings up to 1000 gals/ft^2/hr.

Lime addition at the Newmarket Water Pollution Control Plant improved primary clarifier performance to the extent that one of the three aeration sections was taken out of service - adequate secondary treatment being available from two units. With decreased loadings to aeration sections, economies may be expected from reduced air requirements and improved sludge filterability due to the reduction in waste activated sludge synthesis. In addition, careful consideration may be given to reduced investment in aeration capacity at the design stage of future plant expansions.

Primary treatment plants have operated with a combination of chemical and polymer and have reported improved B.O.D. and suspended solids removal with the initiation of chemical treatment.

Using alum and polymer, the West Windsor Primary Treatment Plant achieved 72 per cent B.O.D. removals, compared to 23 per cent without chemicals. Suspended solids removals increased from 37 per cent to 91 per cent.

Similarly, the Sarnia Water Pollution Control Plant achieved higher degrees of removals with ferric chloride and polymer, up to 86 per cent removal of suspended solids was noted, as compared to 70 per cent without chemical. B.O.D. removals with chemical and polymer increased to 66 per cent from 38

per cent.

We thus see an additional benefit of phosphorus removal in that the pollutant load, in terms of B.O.D and suspended solids imposed on the receiving body, is reduced, in the case of a primary plant.

It is apparent that the retention of these additional solids in the plant, rather than allowing them into the receiving stream, creates additional sludge which must be processed.

While one may look for improved primary settling with the implementation of phosphorus removal, such improvements are not essential to phosphorus removal at a secondary plant using chemical treatment of raw sewage.

To illustrate this point, during a phosphorus removal study at a secondary plant, primary clarifiers became so loaded with sludge that primary clarification was virtually non-existent. At times the primary effluent approximated the composition of incoming sewage in terms of suspended solids and biochemical oxygen demand. Despite this highly inefficient primary clarification, overall phosphorus removal across the plant was excellent, the reason being that what will be called the aluminum phosphate floc carried over into the aeration tanks was effectively settled in the final clarifiers.

This is, naturally, not to be construed as a satisfactory method of operating a sewage treatment plant and, of course, the situation was rectified as soon as possible to provide something more like a secondary treatment plant and less like a total oxidation plant. However, it does indicate that within the overall limits of a secondary plant to handle solids, inefficient primary settling resulting in carry-over of

total phosphorus values from primary to aeration sections does not have a detrimental effect on phosphorus removal across the plant as a whole, when alum and presumably ferric chloride are used.

When using lime in primary treatment some concern exists that phosphate precipitates formed at high pH values in the primary clarifiers will redissolve and release phosphorus when carried over into the aeration sections which are operating at a neutral pH value.

On the other hand, however, it has been reported that soluble phosphates in supernatant from an anaerobic digester processing sludges derived from lime have been low, i.e. in the range of 4 mg/l ortho-phosphorus. This digester was operating near the neutral point and therefore this observation would tend to contradict in some measure the thesis of redissolution of precipitated phosphorus at neutral pH values.

Recent discussions with the Ministry's Research Branch indicate that lime floc carry-over into the aeration sections is detrimental to the overall phosphorus removal process to the extent that the 1 mg/l residual phosphorus requirement <u>may</u> not be possible with lime addition to raw sewage.

In concluding this section a brief note on the effect of high primary effluent pH on aeration section performance is appropriate.

It has been found that at the effluent pH's noted in Ministry studies, the carbon dioxide evolved during biological activity has been adequate to promptly neutralize the alkaline pH.

When using lime addition, the potential for aeration section failure appears directly proportional to the reliability of

of the lime metering equipment and its "fail-safe" ability to avoid excessive lime dosages to the system. This is obviously not to be interpreted as a criticism of presently available lime feeder units, but as a precautionary note to anyone involved in the installation of facilities for lime feeding.

Over the past eighteen months to two years, the bulk of data on phosphorus removal has been developed using only one point of addition, that point being determined by jar tests.

In view of the variation in sewage flows and plant operation throughout a given year, the point of addition (i.e. primary or secondary) and indeed, the chemical which is best suited for a particular plant may only be chosen after prolonged periods of operation using the available combinations of chemical and point of addition. For this reason the various processes for phosphorus removal as determined by the present series of nutrient removal studies, although providing a viable means of phosphorus removal, may not provide the optimum scheme for a particular plant. It is therefore the responsibility of designers of phosphorus removal facilities to ensure that the plant under consideration is provided with the maximum degree of flexibility in order that plant operators may, if they so desire, study on an extended basis the various options open to them for phosphorus removal by chemical addition.

PHOSPHORUS REMOVAL DESIGN SEMINAR

SESSION 3

CHEMICAL PRECIPITATION FOR BIOLOGICAL AND POSTBIOLOGICAL TREATMENT

By J.D. Norman, Ph.D.
Pollutech Pollution Advisory Services Limited.

The information presented in these notes is based on observations of chemical precipitation at full-scale treatment plants in several plants in Ontario. Comments are made on some of the factors affecting performance of chemical precipitation processes and the effect or lack of effect of several variables that were tested under full-scale conditions. In some cases, these data can be regarded as an inference only, due to the limited programs of testing, therefore positive conclusions should not be generalized.

CHOICE OF CHEMICAL

The choice of chemical used for full-scale testing for the Ontario problem is determined on the basis of cost projections developed from the jar testing procedure. Normally, only one chemical is evaluated, for an eight-week period, at each treatment plant, in full-scale tests.

However, we have observed in all cases that the full-scale tests required less chemical than the jar test predictions. Therefore, it may be that the economic evaluation to determine the choice of chemical could prove different if the economic evaluation was conducted on a plant scale.

POINT OF APPLICATION

While theoretically there is some choice in the point at which chemical is applied to the treatment plant, in actual fact, this is usually limited by the physical and mechanical features of existing treatment plants. For the most part, limitations and flexibility in the original design of the biological treatment plant has severely restricted the extent to which the point of chemical application could be varied.

For maximum effectiveness of chemical precipitation, theoretical considerations would indicate that the chemical should be well dispersed with the mixed liquor and permitted to settle under quiescent conditions in the final clarifier. In normal circumstances of chemical treatment, the rapid mix period varies from several seconds to a fewminutes. There are some treatment plants in which there is a pipe or trough between the aeration tank and the final clarifier in which there is sufficient turbulence to provide the desired mixing. When there is no such turbulence, little choice remains but to provide the mixing in the aeration tank, preferably at a point near the output end.

While it may appear that the aeration tank itself on the whole would be a very good mixer, one problem immediately comes to light.

- The holding time is extremely long and therefore no advantage is gained by floc formation due to the extreme turbulence in the tank and since only a few seconds are required for dispersal.

For the case of pickle liquor, where it requires oxidization in order to provide iron in the trivalent form, it is logical to use the aeration tank as an oxidizer. In one application with which we were involved, we chemically oxidized the pickle liquor in the laboratory in order to obtain predictions and in the field tests obtained comparable results when the pickle liquor was oxidized in the aeration tank.

RATE OF CHEMICAL APPLICATION

The initial selection of a chemical dosage rate is based on the results of the jar test predictions.

- Usually, this dosage rate turns out to be conservative and can be cut back after a short period of time as the plant comes to equilibrium.

  The effect of chemical dosage on effluent quality is not clearcut and not a topic on which a generalized statement can be made, but generally a measurable improvement in overall performance is observed.

  In the long term, obviously the higher the dosing rate the lower the Phosphorus residual (to a given limit) but in the short term, fluctuations in dosing rate have little effect on Phosphorus residual.

VARIABLES AFFECTING CHEMICAL DOSAGE

In an attempt to gain an understanding of why some anomalies occurred during chemical precipitation of biological treatment plant effluents, several test programs were carried out in order to determine whether any correlations could be found between chemical parameters in waste water and the amount of alum to achieve a 1 ppm phosphorus residual in secondary effluent.

- FIGURE I shows that there is no correlation between the pH of the wastewater before chemical addition and the chemical dosage.

Furthermore, no correlations could be found between such wastewater parameters as alkalinity, hardness, turbidity, or conductivity .(FIGURES II, III, IV and V).

CONTROL OF CHEMICAL FEED

The results shown on FIGURES I to V , above, indicate that:

- Parameters which are easy to measure were not shown to bear any relation to chemical dosage requirements or to effluent phosphorus criteria. Therefore, the use of these parameters to control chemical dosage does not appear encouraging.

  Further, it has been our experience that the variations from one plant to another are considerably greater than the variations in any given plant, therefore the likelihood of obtaining some useful controller would seem to be minimal.

  Above all, the insensitivity of the normal activated sludge system to chemical precipitation applications appears to dictate not only that a chemical controller would be redundant but also why it is so.

- FIGURE VI shows a schematic of a treatment plant in a location where chemicals could be mixed at the outlet from an aeration tank and soluble phosphorus monitored at the inlet to the final clarifier. Once this system reached equilibrium, it became apparent that there was a large phosphorus reduction in the aeration tank, due solely to the influence of metals in the return sludge. Hence, any device controlling chemical dosage only had control over changes from about 2ppm phosphorus to less than 1/2 ppm.

  On all the applications we have seen to date, there would be no advantage whatever in controlling chemical

application proportional to phosphorus mass flow. Proposals which suggest that mass flow be used as a parameter have not given consideration to the difficulty and expense of measuring phosphorus and making the mathematical computation. It has been our observation that flow measurement alone, while much simpler and much more economical, would provide just as close a control.

EFFECT ON PLANT OPERATION

Due to the increased amount of solids carried in the system because of metal ions and their complexes, increases are required in the mixed liquor suspended solids concentration in order to maintain a similar level of organisms to that which previously existed.

Evaluations on the effect on equipment such as pumps, diffusers and other moving mechanical parts, can realistically be assessed only after a long period of either ferric chloride or aluminum sulphate application.

The effect on sludge quantity and quality is not yet known.

- The amount of sludge as well as the density of sludge produced is bound to be affected and probably will have a noticeable effect where raw sludge is handled.

- Where the chemical sludge is digested, an extensive period of long-term evaluation will be required before there is positive evidence as to whether or not phosphorus will resolublize and whether or not there will be any other side effects.

In cases where we were able to make observations simultaneously on two halves of a treatment plant, effluent BOD and suspended solids always appeared to be better than the original plant and certainly was not any worse.

SUMMARY

Our experience and observations to date indicate to us that there are no stock answers when it comes to chemical precipitation systems added to biological or postbiological effluents.

- There are no common symptoms.
- There are no common solutions.

However the solutions are not difficult to obtain for any given treatment plant.

- It just requires data
- and it requires patience
- and it requires some practical innovation rather than large capital costs.

The jar testing procedure is consistent for a given waste, but the sewage itself is not consistent.

- Therefore it is critical that the time at which jar tests are done and the frequency and randomness of testing be properly guarded.

Equipment for chemical application is inexpensive and quite portable, therefore each plant can be experimented with in order to find the best situation for any particular problem.

Chemical precipitation systems should provide improved effluent quality in addition to phosphorus removal.

- BOD and Suspended Solids should show an improvement;
- Metals in the effluent should be precipitated and retained in the system;
- Other benefits of chemical precipitation may not come to light until many more measurements are taken.

Eight weeks is not a sufficiently long period of full-scale testing in order to optimize chemical dosing rates.

SECONDARY EFFLUENT: AMOUNT OF ALUMINUM REQUIRED TO ACHIEVE 1 ppm PHOSPHORUS RESIDUAL VS pH BEFORE CHEMICAL ADDITION

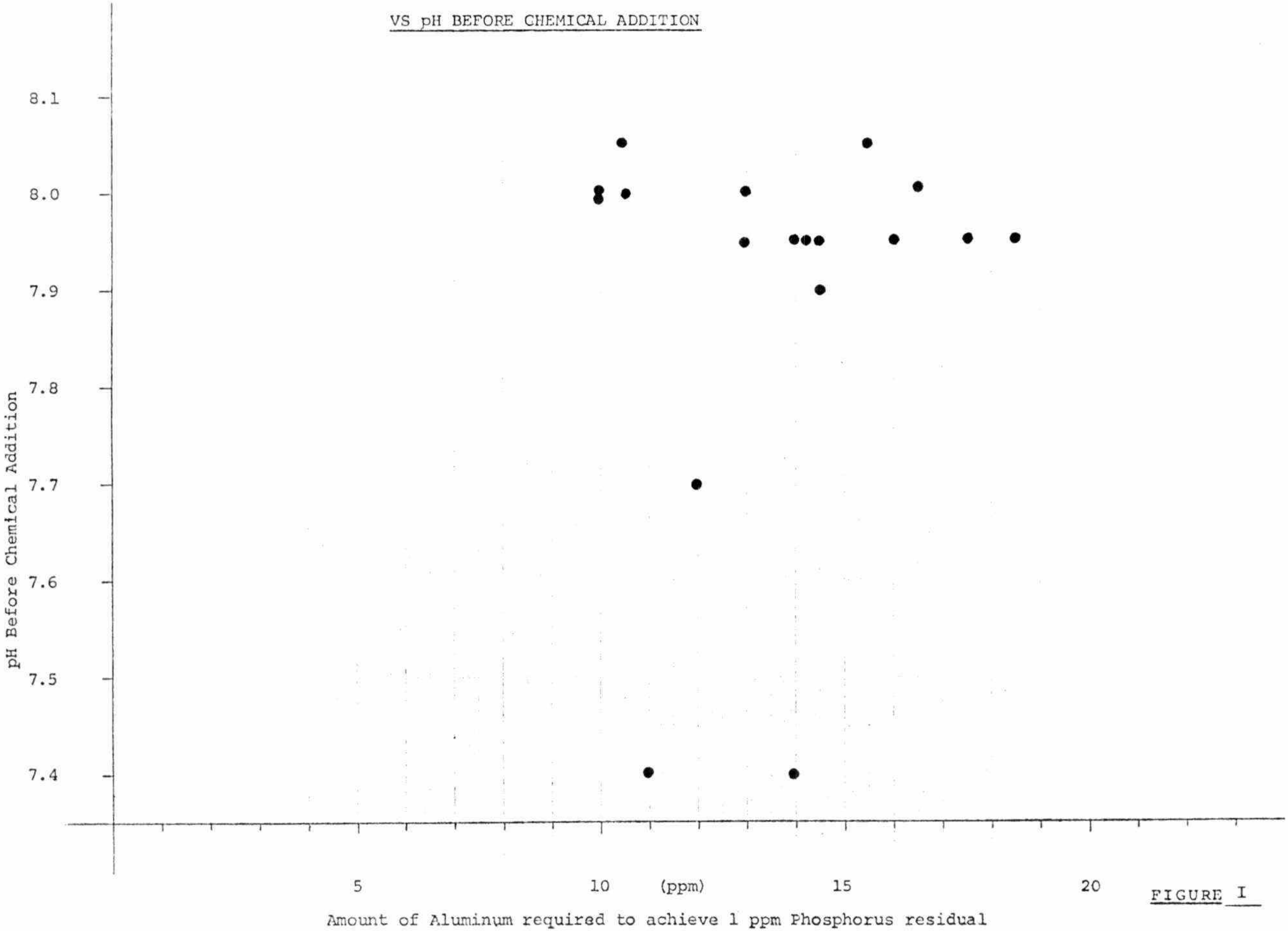


FIGURE I

SECONDARY EFFLUENT: AMOUNT OF ALUMINUM REQUIRED TO ACHIEVE 1 ppm PHOSPHORUS RESIDUAL VS TOTAL ALKALINITY BEFORE CHEMICAL ADDITION

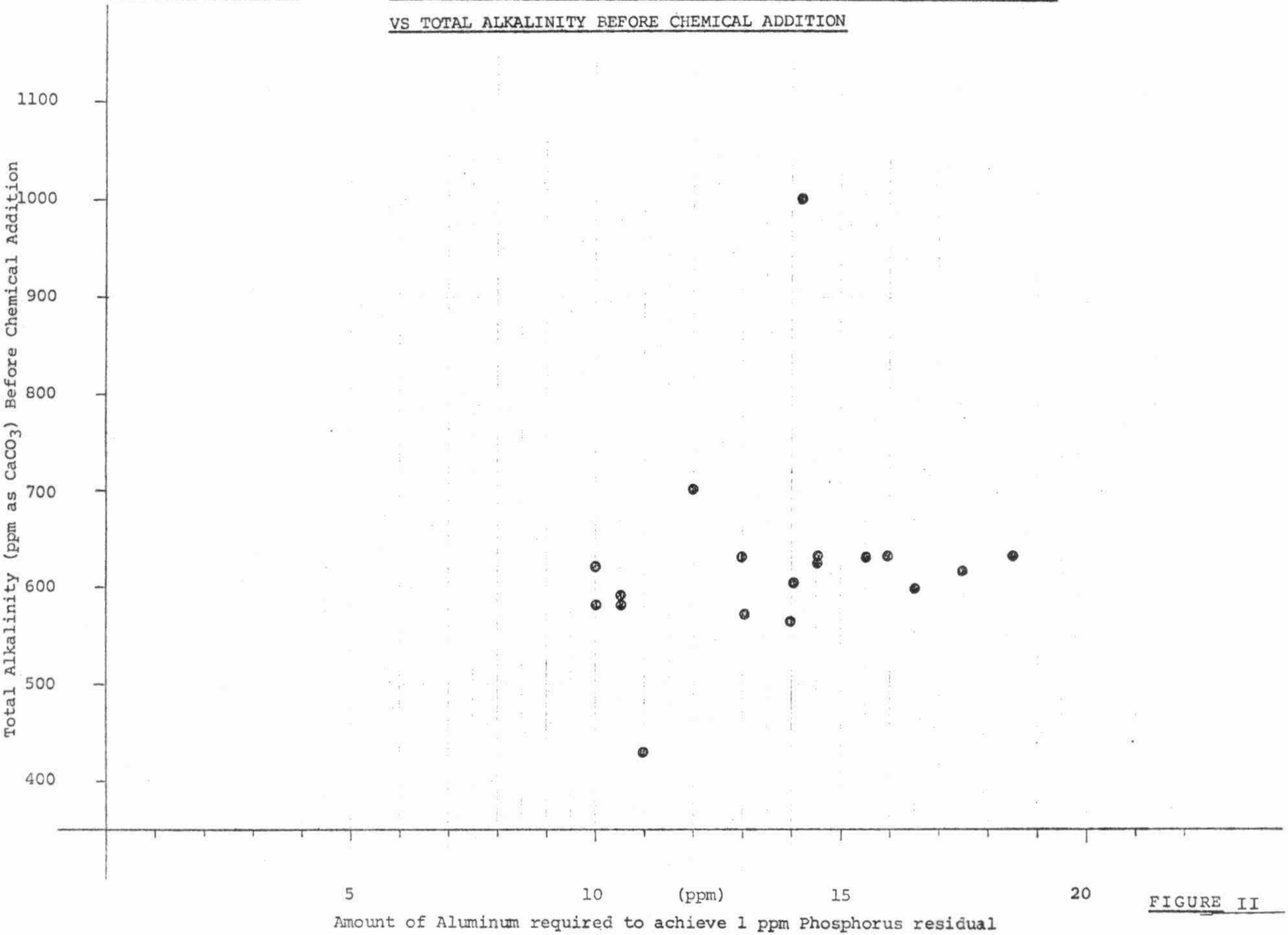


FIGURE II

SECONDARY EFFLUENT: AMOUNT OF ALUMINUM REQUIRED TO ACHIEVE 1 ppm PHOSPHORUS RESIDUAL VS HARDNESS BEFORE CHEMICAL ADDITION

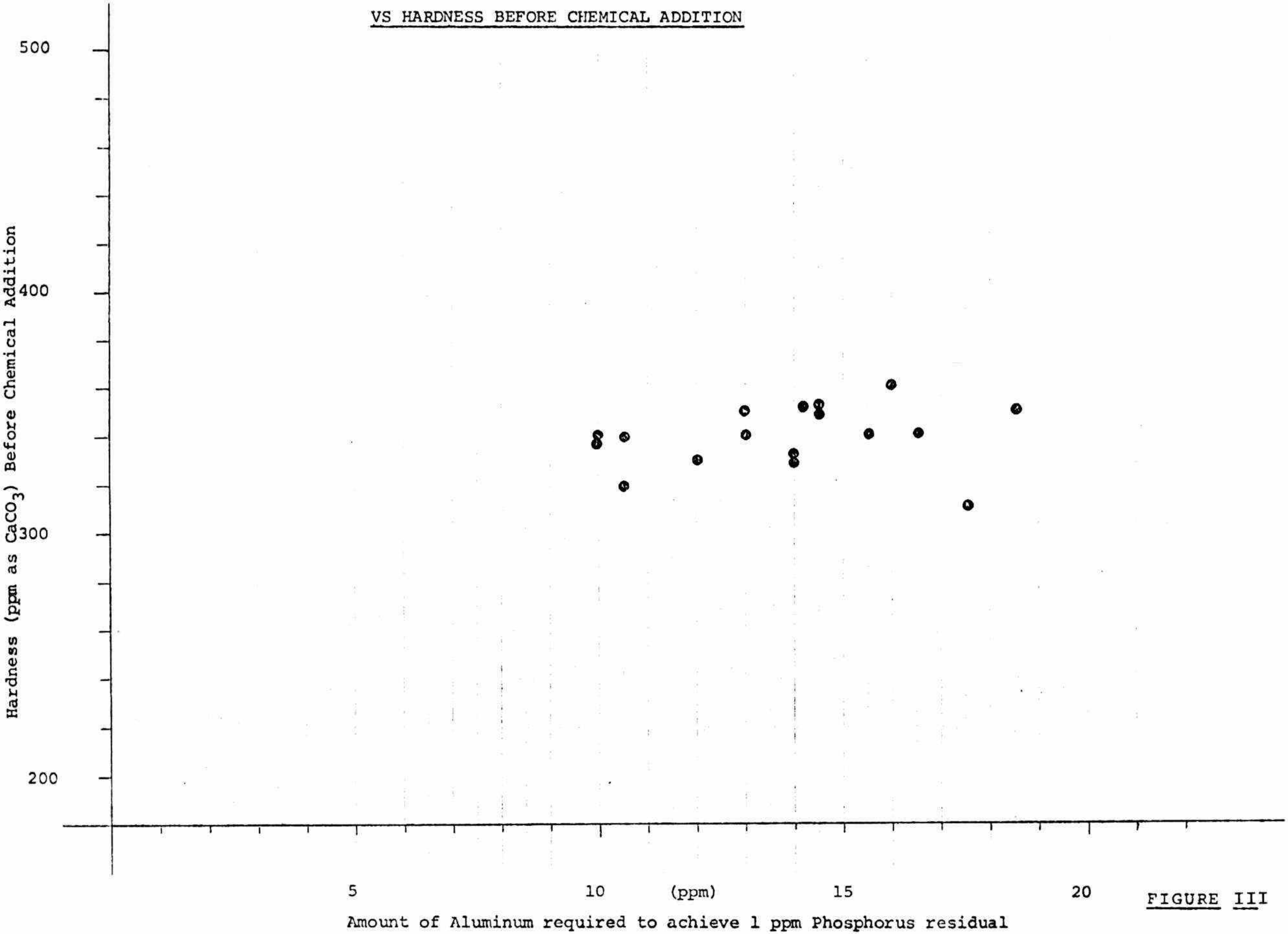


FIGURE III

SECONDARY EFFLUENT: AMOUNT OF ALUMINUM REQUIRED TO ACHIEVE 1 ppm PHOSPHORUS RESIDUAL VS TURBIDITY BEFORE CHEMICAL ADDITION

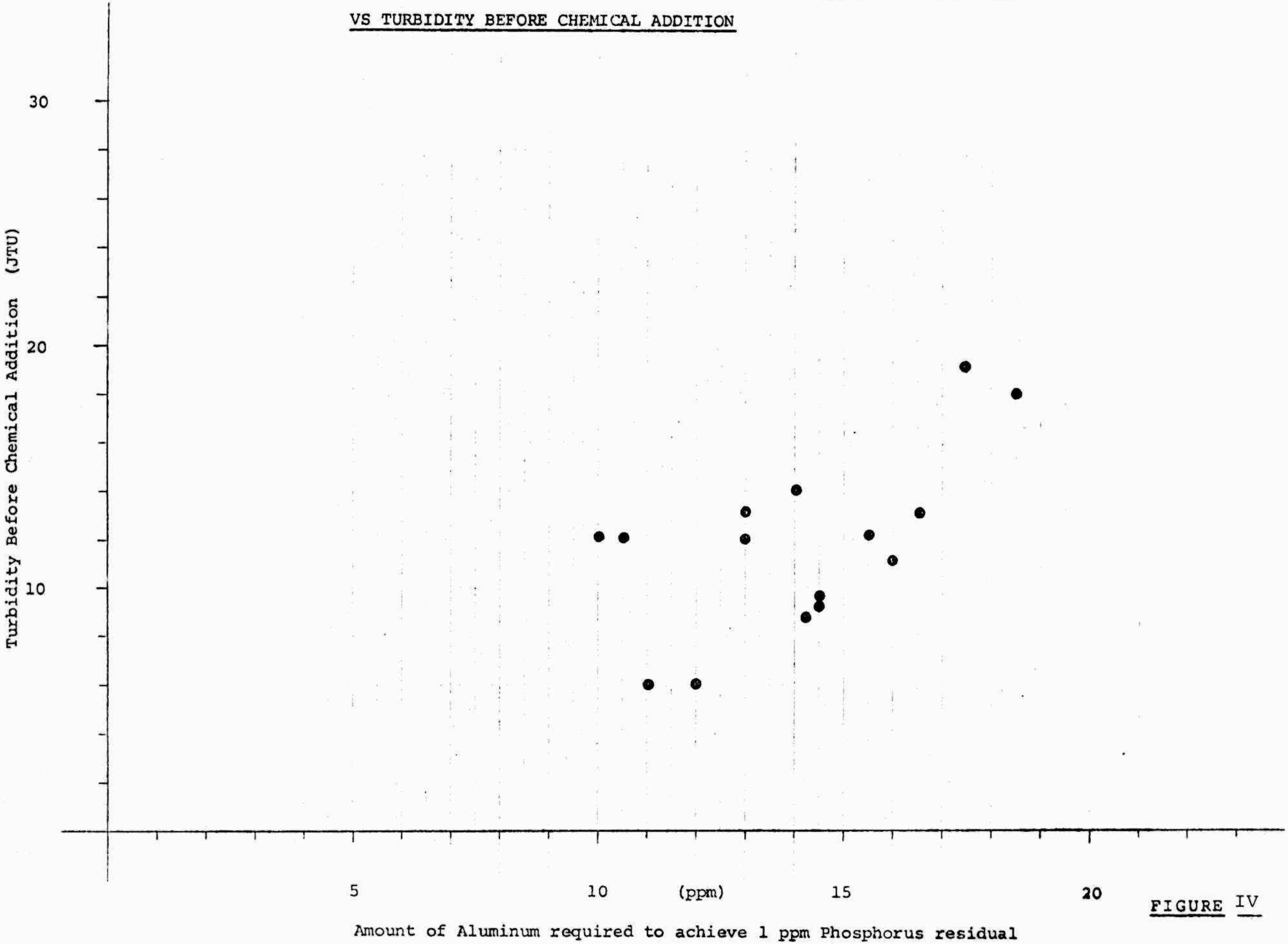


FIGURE IV

SECONDARY EFFLUENT: AMOUNT OF ALUMINUM REQUIRED TO ACHIEVE 1 ppm PHOSPHORUS RESIDUAL VS CONDUCTIVITY BEFORE CHEMICAL ADDITION

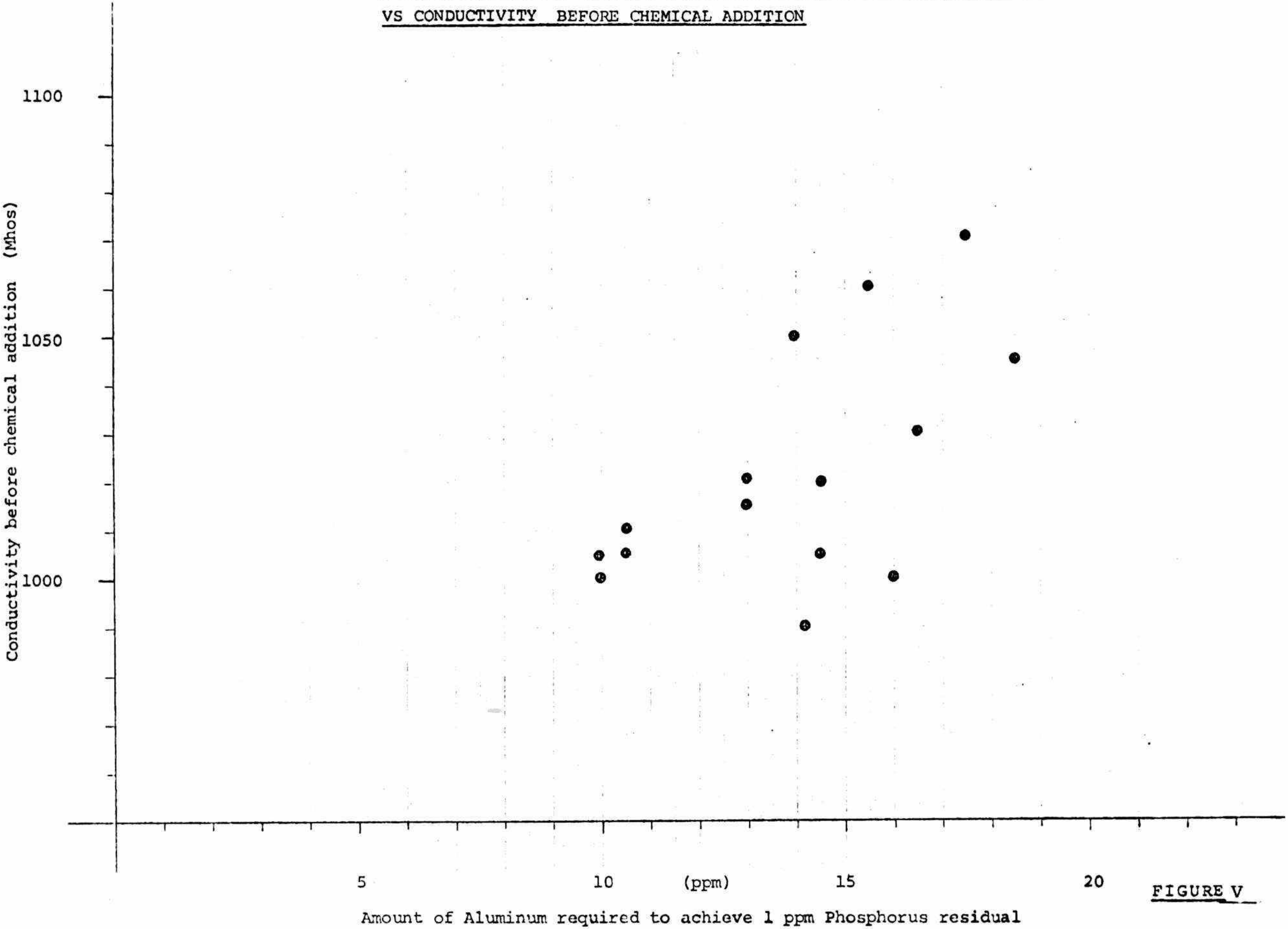


FIGURE V

CHEMICAL DOSAGE CONTROL

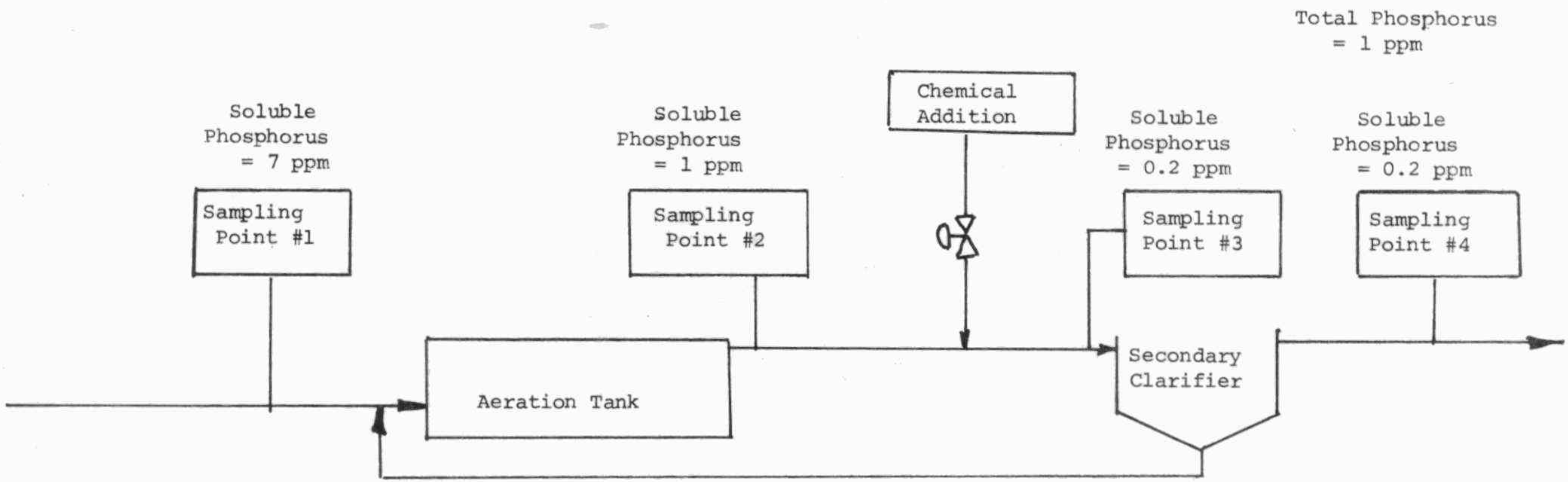


FIGURE VI

PHOSPHORUS REMOVAL IN SEASONAL RETENTION LAGOONS BY BATCH CHEMICAL PRECIPITATION

by:

H. J. Graham and R. B. Hunsinger

Ontario Ministry of the Environment
Research Branch
135 St. Clair Avenue, West
Toronto, Ontario

TABLE OF CONTENTS

SUMMARY

Three chemical precipitants have been tested as a means of phosphorus removal in the batch chemical treatment of seasonal retention lagoons. Six treatments have been carried out with alum, three with ferric chloride and one with lime. The required dosage was determined by jar tests using the pond contents. It was found that these jar tests were highly reliable in predicting the post-treatment results in the lagoons.

The chemicals were dispersed and mixed with outboard motorboats. It took two to three man hours per acre (5-7.5 man hours per ha) to treat a lagoon with a liquid chemical, and 13 to 25 man hours per acre (32½ to 62 man hours per ha) to treat with a dry chemical. Lagoon discharge was usually begun the day after treatment and continued for an average of eight days.

Both alum and ferric chloride produced a high quality effluent, low in phosphorus and BOD. The lime application initially produced a high quality effluent, but deteriorated rapidly over the draw down period.

PHOSPHORUS REMOVAL IN SEASONAL RETENTION LAGOONS BY BATCH CHEMICAL PRECIPITATION

INTRODUCTION

As a result of the International Joint Commission report of 1969, the Province of Ontario adopted a policy requiring 80% phosphorus removal from wastewater treatment plant influents eventually entering the Lower Great Lakes and inland recreational waters, by the end of 1973 or 1975, depending on the location in the Province. This was later modified to an effluent total phosphorus level of 1.0 mg/l or less (Canada/U.S. Agreement, 1972). One practical means of effecting this kind of phosphorus reduction in the effluent from waste stabilization ponds is chemical treatment within the existing facility, either through continuous or batch chemical addition. The latter would be more advantageous in a seasonal retention lagoon because of the lower capital and operating costs.

The areas in which additional information was required regarding the batch chemical treatment of lagoons were:

1) chemicals that can be used effectively for phosphorus removal;
2) the most efficient means of dispersing the chemicals;
3) possible recirculation of the phosphorus after treatment; and
4) cumulative effect in repeated applications.

To answer these questions, various chemicals were used in lab studies, "in-situ" studies and numerous full scale treatments in different lagoons.

BACKGROUND

In recent years eutrophication, or the over-abundance of nutrients, has become a very serious problem in the Lower Great Lakes. It is generally accepted that reducing the phosphorus loads coming into these lakes will improve the situation (Sawyer, 1968; Shapiro, 1970; Vallentyne et al, 1970; and Hamilton, 1971). As stated earlier the International Joint Commission has acted upon this information and put forward guidelines that will strictly limit the amount of phosphorus entering these lakes from sewage effluents.

One means of reducing the phosphorus is by chemical precipitation using one of the common coagulants, such as aluminum sulphate, ferric chloride or lime. This form of treatment has recently been associated with tertiary treatment for conventional sewage treatment plants (Lea et al, 1954; Malhotra et al, 1964; Nilsson, 1969; and Vollenweider, 1968). However, emptying into the Lower Great Lakes basin are many waste stabilization ponds, some of which are operated on a seasonal retention (fill-and-draw) basis. The problem of how to treat these installations had to be considered. It was decided to try a batch type of chemical application, and in order to distribute the chemical in a reasonably uniform manner within the lagoon and achieve sufficient mixing, motor boats were used containing tanks which discharged the liquid or slurry into the prop-wash. This concept of batch chemical treatment, to reduce phosphorus levels, has also been used on two lakes (Jernelov, 1970 and Wall et al, 1971).

METHODS

1) Site Evaluation

On the primary visit to the experimental site the physical facilities were examined. The access road to the lagoon was visually assessed for 50 ton (45 metric tons) carrying capacity in early spring and late fall. If heavy vehicular delivery did not seem feasible the possibility of piping the chemical was examined.

The structural facilities were checked to insure that diversion of influent was possible during treatment and discharge on the multiple cell installation and also that separate discharge facilities were available.

The mean depth of the lagoon was ascertained by taking numerous random soundings with a graduated weighed line. The lagoon was checked for obstructions that would make power boat operation hazardous.

2) Dosage Determination

A 10 gallon (45.5 l) sample of surface lagoon water was collected from each cell to be treated. It was felt that the modes of operation, parallel or series, the age of the lagoon etc. could possibly effect a different dosage requirement in cells of the same system.

The 10 gallon (45.5 l) samples were returned to the laboratory for jar testing in order to determine the optimum chemical and dosage required with relation to performance and cost.

The jar testing consisted of adding a dosage range of the test chemical (i.e., Lime 50-350 mg/l; Alum 50-300 mg/l; Ferric Chloride 5-30 mg/l as Fe^{+3}) to 2 litre samples of the lagoon water being mixed with a Phipps and Bird multiple laboratory stirrer at 200 rpm, continuing this rapid mixing for 5 minutes, followed by 15 minutes of slow mixing

at 30 rpm. Two to four hours after mixing, the supernatant was sampled. Total phosphorus analyses were then carried out on the supernatant samples and untreated control samples.

Total phosphorus reduction to 1 mg/l or less was the prime criterion used to determine dosage. The total phosphorus results were plotted on an approximate equal chemical cost graph (Figure 1). The dosage used in the full scale tests was the one that reduced the total phosphorus to between 0.5 - 0.2 mg/l. This level is lower than the criterion of 1 mg/l residual total phosphorus, but it was felt that the chemical would be less efficient in the field than in the jar test.

3) Application

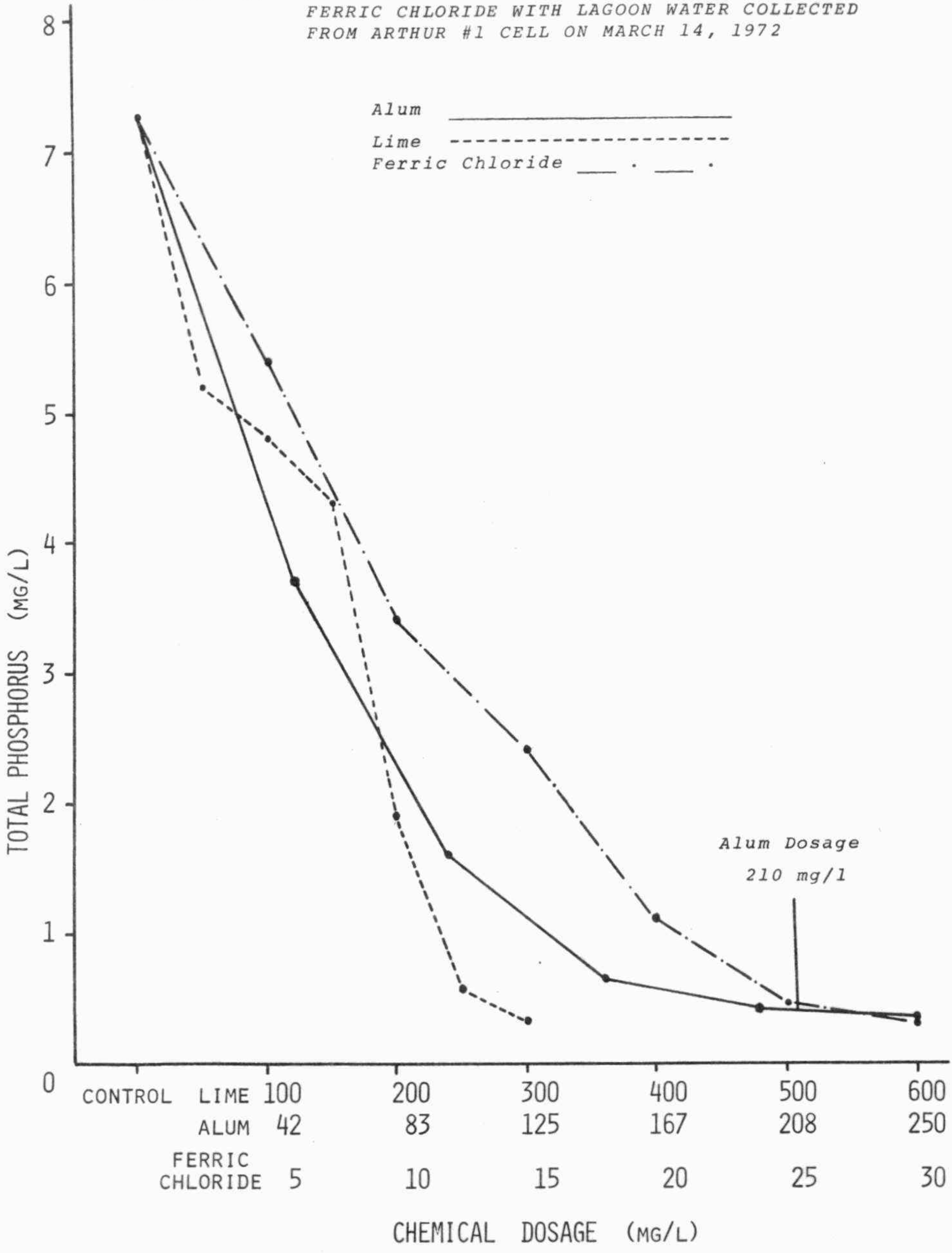
Liquid Chemical

Prior to the application, the experimental lagoon sites were prepared for treatment. A small portable floating dock approximately 6 feet x 12 feet (1.83 x 3.66 m), was anchored at the edge of the cell near the spot where the chemical delivery truck would be. The boats (usually two) were launched into the lagoon. The inflow of raw sewage was diverted to another cell in the multiple cell installation. In cases where the chemical delivery truck was unable to get close enough for direct discharge to the boats, the piping system for chemical delivery was also installed at this time.

The chemical was delivered to the site by a tank truck, and a 50 foot (15.2 m) length of hose supplied by the carrier, was run from the tanker to the dock. The chemical was normally delivered directly from the tank truck to the tanks in the boats at the dock.

The boats used in the experimental treatments were 16 foot (4.88 m) aluminum outboard motorboats, equipped with 40 H.P. (40.4 metric H.P.) motors. A 150 gallon (681 l)

FIGURE 1. RESULTS OF JAR TESTS USING ALUM, LIME AND FERRIC CHLORIDE WITH LAGOON WATER COLLECTED FROM ARTHUR #1 CELL ON MARCH 14, 1972



rectangular plastic tank was anchored amidships. A 2 inch (5.1 cm) valved plastic syphon was attached to the stern of the tank near the bottom, and proceeded over the transom and down to a level just below the bottom of the boat. A 90^{o} elbow directed the chemical into the prop-wash. In order to facilitate starting the syphon, a hole, of approximately 1 inch (2.5 cm) diameter, was cut into the leading edge of the last 90^{o} elbow. A more permanent installation was later installed with direct discharge through the transom.

Personnel who were within splash distance of the chemical wore rubber rain suits, plastic face shields and rubber gloves. The protective clothing was more critical in the application using ferric chloride than it was in the alum applications.

Dry Chemicals

The site preparation for dry chemical included the dock installation, boat launching and sewage diversion, as outlined in the section on liquid chemicals. In addition, a 600 gallon (2720 l) slurry mixing tank was located adjacent to the lagoons. A gasoline driven pump was used to supply water to the slurry tank. A chemical transfer line, either pump or syphon, was installed from the slurry tank to the loading dock. A platform was built to hold the dry chemicals off the ground.

The dry chemical was delivered to the site in paper bags or small drums on transport trucks and unloaded either manually or by forklift onto the storage platform.

The chemical was carried from the storage platform to the 600 gallon (2720 l) slurry tank where it was mixed with the water pumped from the lagoon and then delivered to the boat tank via a chemical transfer line.

The same boats used in the liquid application were used in the dry chemical work. In addition to the 150 gallon (680 l) plastic tanks and the syphon dispersal equipment

each boat was equipped with, a 110 volt generator connected to an electric mixer mounted on the 150 gallon (680 l) tank. A man with a paddle was as effective as a mixer for keeping the slurry in suspension. This additional equipment was not necessary for the dry chemical that went into solution rather than slurry.

In one small cell application (1 acre) (0.4 ha) using dry ferric chloride, the chemical solution was mixed in the boat tanks, thus bypassing the shore slurry tank. A pump supplied make-up water from the lagoons to the boat tanks. The chemical was carried from the boats and dumped directly into the tanks, where it was mixed and then dispersed in the usual manner. The unstable and restrictive work area on the dock and in the boat made this adaptation of this method difficult and somewhat hazardous.

Protective clothing as outlined in the previous wet chemical system became more critical in the dry chemical system, with the extra handling involved. The dry chemical also introduced a dust problem, necessitating the wearing of dust masks.

4) Discharge of the Treated Cells

The floc formed by the chemical precipitants was given approximately 15 hours to settle out before discharging of pond contents began, usually the morning following treatment.

Discharge was carried out as quickly as possible, given the physical limitation of the effluent structures, and the chemical and hydraulic loading limits of the receiving stream. The residual depth of water left in the lagoon after treatment was dependent on the design of the effluent structure. These residual depths varied from a few inches to two feet.

STUDY PROGRAM

1) Feasibility of Batch Treatment

Preliminary work on batch treatment was carried out at the Arthur, Ontario lagoons in the latter half of 1971. Arthur was chosen because it fulfilled the criteria outlined in the methods section, and had a sewage of mainly domestic origin thus avoiding any interference from unusual industrial wastes.

The dosage in this first treatment was determined by jar tests and in situ studies carried out in a large cylinder in the lagoon, rather than just the conventional jar tests as used in subsequent treatments.

Full scale treatment was carried out in November, 1971, on the middle 5 acre (2.0 ha) cell, using liquid alum handled in the method previously outlined.

2) Alum

In order to verify the results obtained in Arthur in 1971, one cell (15 acres) (6.0 ha) of the Tavistock lagoon system was treated in April, 1972. Alum was discharged from the tanker truck directly to the boats as outlined above. As noted below, alum was also used in full scale applications on a large cell treatment simulation and also in testing the cumulative effects of batch treatment.

3) Ferric Chloride

Ferric chloride as a precipitant in batch treatment was first tested on the small 2 acre (0.8 ha) cell at Geneva Park near Orillia, Ontario in May, 1972. The method used was the modified version of the dry chemical method where the chemical was mixed in the boat tanks.

In order to check the results obtained in the Geneva Park treatment and also to assess the behaviour of the precipitant over longer draw-down periods, two subsequent

treatments were carried out. Both of these treatments used the liquid chemical method. The first was carried out on the 7 acre (2.8 ha) #3 cell at the Arthur lagoons in October, 1972, and the second treatment was carried out on the 16 acre (6.4 ha) single cell installation at Sutton, Ontario in November, 1972.

4) Lime

The feasibility of using hydrated lime as the precipitant in the batch treatment method was assessed on one 7 acre (2.8 ha) cell of the Tottenham lagoon system in May, 1972.

The application was carried out over a three day period using the technique outlined for dry chemical application in the methods section above.

5) Large Cell Application

The feasibility of treating cells greater than 25 acres (10 ha) in size was tested in a simulated manner using the 5 acre (2.0 ha) #1 cell at Arthur, Ontario in May, 1972. The dosage was applied in three equal portions over three consecutive days. The standard liquid chemical method of treatment was used.

6) Cumulative Effect of Batch Treatment

To assess the cumulative effects of batch treating one cell on a regular basis the first cell treated in this program, namely the 5 acre (2.0 ha) #2 cell at Arthur, has been treated a total of four times over an 18 month period. The first treatment as noted above was carried out in November, 1971, followed by treatments in May, 1972, October, 1972, and finally May, 1973.

DISCUSSION OF RESULTS

1) Full Scale Application Dosages

The dosages used in full scale treatments as predicted by the jar tests are as follows:

Arthur #2 cell, 1971, 325 mg/l alum

Arthur #1 cell, 1972, 210 mg/l alum (prolonged application over three days)

Arthur #2 cell, May 1972, 125 mg/l alum

Arthur #2 cell, October 1972, 150 mg/l alum

Arthur #2 cell, May 1973, 150 mg/l alum

Tavistock, 1972, 170 mg/l alum

Tottenham, 1972, 250 mg/l lime

Geneva Park, 1972, 17 mg/l ferric chloride as Fe^{3+}

Arthur #3 cell, 1972, 22 mg/l ferric chloride as Fe^{3+}

Sutton, 1972, 20 mg/l ferric chloride as Fe^{3+}

Wingham, 1972, 100 mg/l alum

2) Total Phosphorus

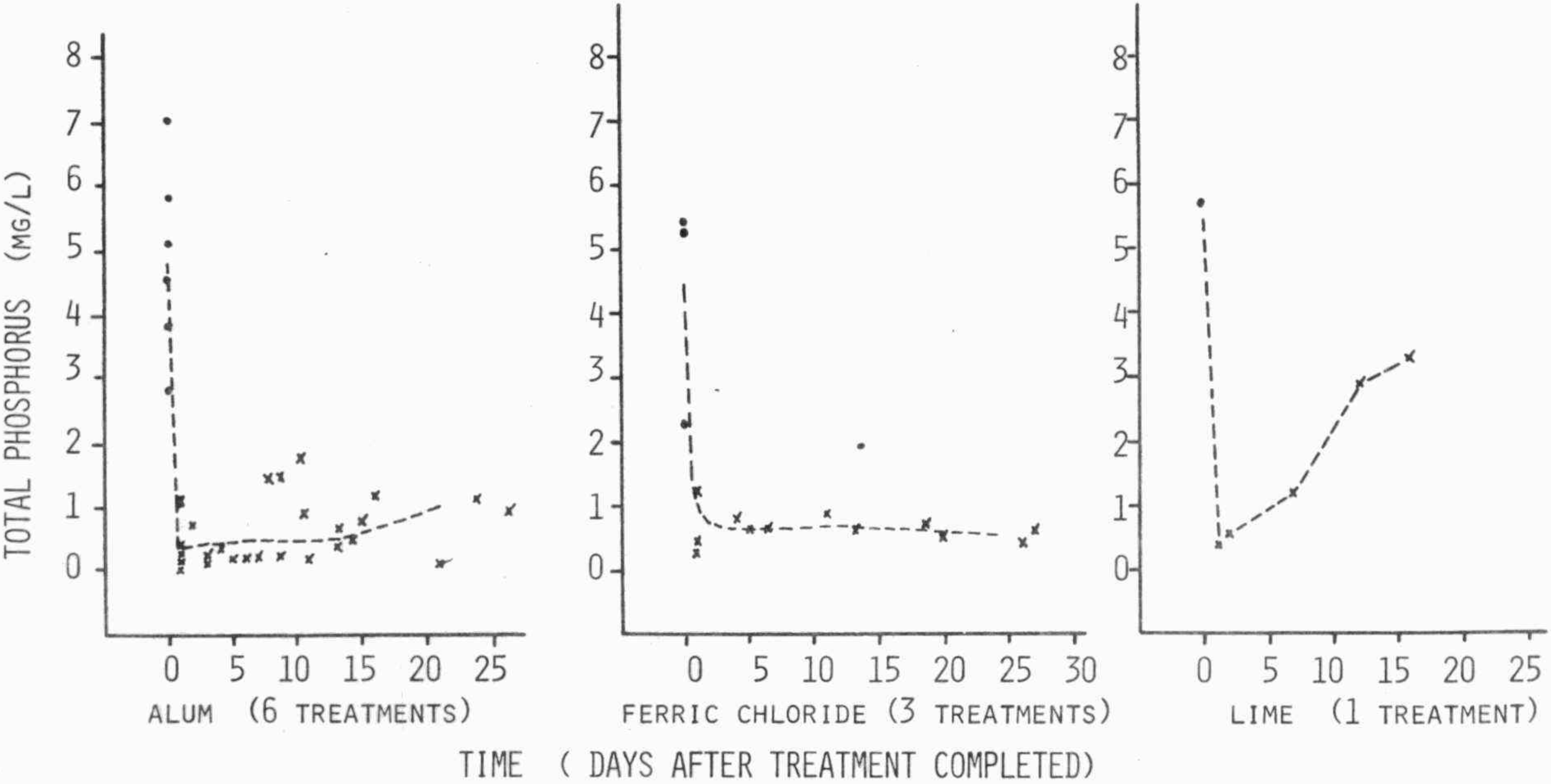
As can be seen in Figure 2 the three chemicals used all effected a substantial decrease in the total phosphorus by the day following the batch treatment. At this time most of the alum treated lagoons had a total phosphorus concentration of from 0.1 to 0.2 mg/l; however, the two lagoons treated at only 100 and 125 mg/l alum had a total phosphorus of 1.0 and 1.1 mg/l respectively. By thirteen days after treatment there was usually a slight increase in the total phosphorus, although this seldom exceeded 1.0 mg/l.

In the case of the ferric chloride treatments, the initial post-treatment levels of total phosphorus were usually not as low as with alum, but there was no phosphorus return, up to twenty-seven days after treatment.

The lime caused an initial drop in the total

FIGURE 2. RESPONSE OF TOTAL PHOSPHORUS IN SEASONAL RETENTION LAGOONS AFTER BATCH TREATMENT WITH THREE CHEMICALS

. *results before treatment*
x *results after treatment completed*



phosphorus, but the return was rapid and was above 1.0 mg/l during the mean draw down period.

3) Soluble Phosphorus

By the day after treatment all three chemicals again effected a considerable decrease in the soluble phosphorus (Figure 3). At this time the soluble phosphorus in most of the alum treated lagoons was 0.1 to 0.2 mg/l, essentially the same as the total phosphorus concentration. Over the observation period there was no significant change. Approximately the same was found after treating with ferric chloride.

The lime treatments caused an initial reduction in the soluble phosphorus but there was an increase during the draw-down. The post-treatment soluble phosphorus peak (Figure 3) corresponded to a decrease in the pond pH values.

4) BOD

The three chemicals tested caused an initial decrease in the BOD following batch treatment (Figure 4). In three of the alum treated lagoons, the BOD continued to decrease during the mean draw-down period and was below 10 mg/l after three days, although in one of these lagoons by nine days after treatment there was an increase to about 18 mg/l. The fourth alum treated lagoon received a dosage of only 125 mg/l alum and the BOD decreased to 16 mg/l just after the treatment, but increased during the mean draw-down period to about 20 mg/l.

The pretreatment BOD levels in the lagoons to be treated with ferric chloride were all very low. After the batch treatment there was a slight decrease and no subsequent increase.

The lime caused an initial reduction in the BOD, but after eight days there was a drastic increase in BOD as is shown in Figure 4.

FIGURE 3. RESPONSE OF SOLUBLE PHOSPHORUS IN SEASONAL RETENTION LAGOONS FOLLOWING BATCH CHEMICAL TREATMENT

. *results before treatment*
x *results after treatment completed*

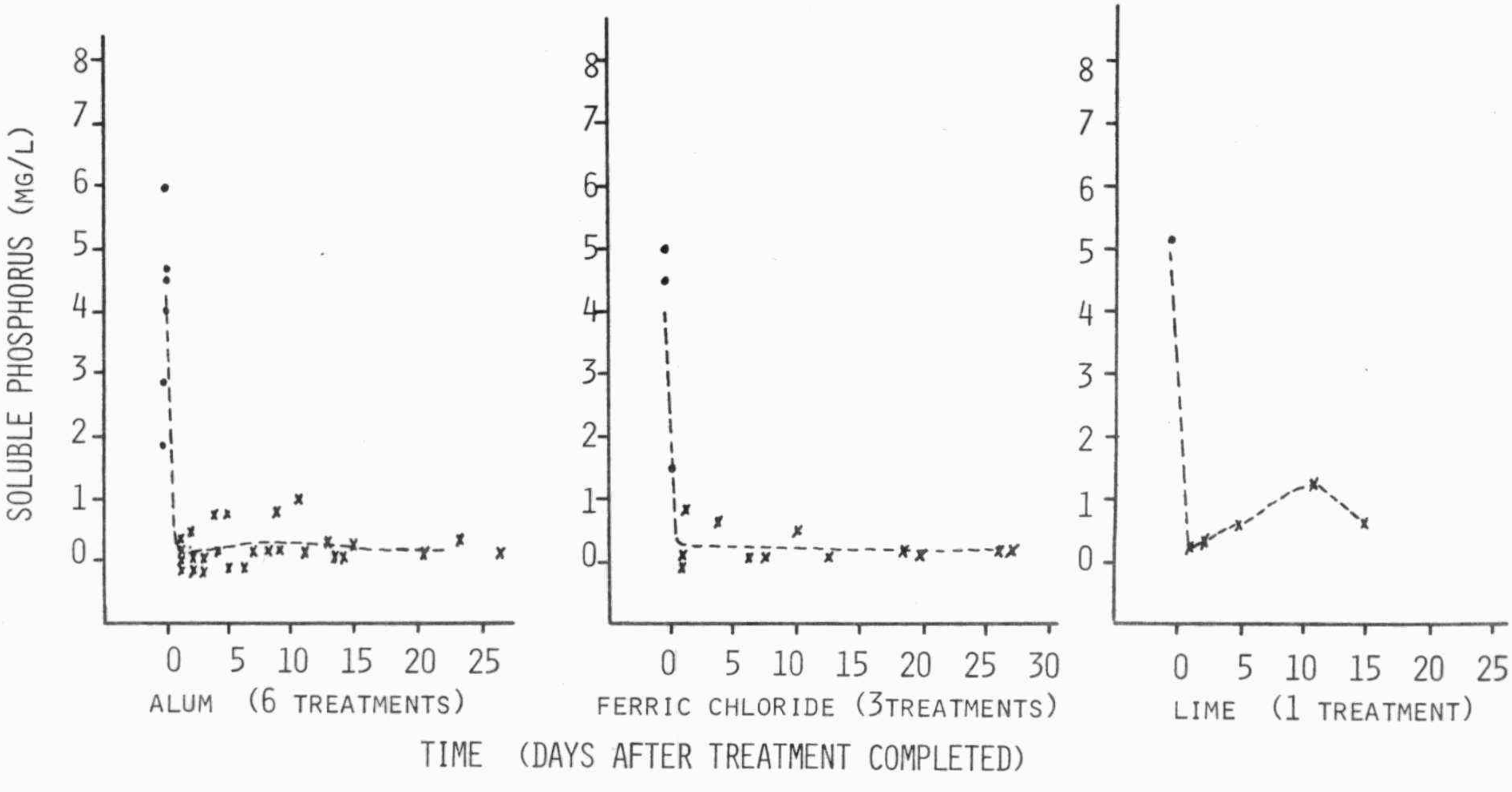
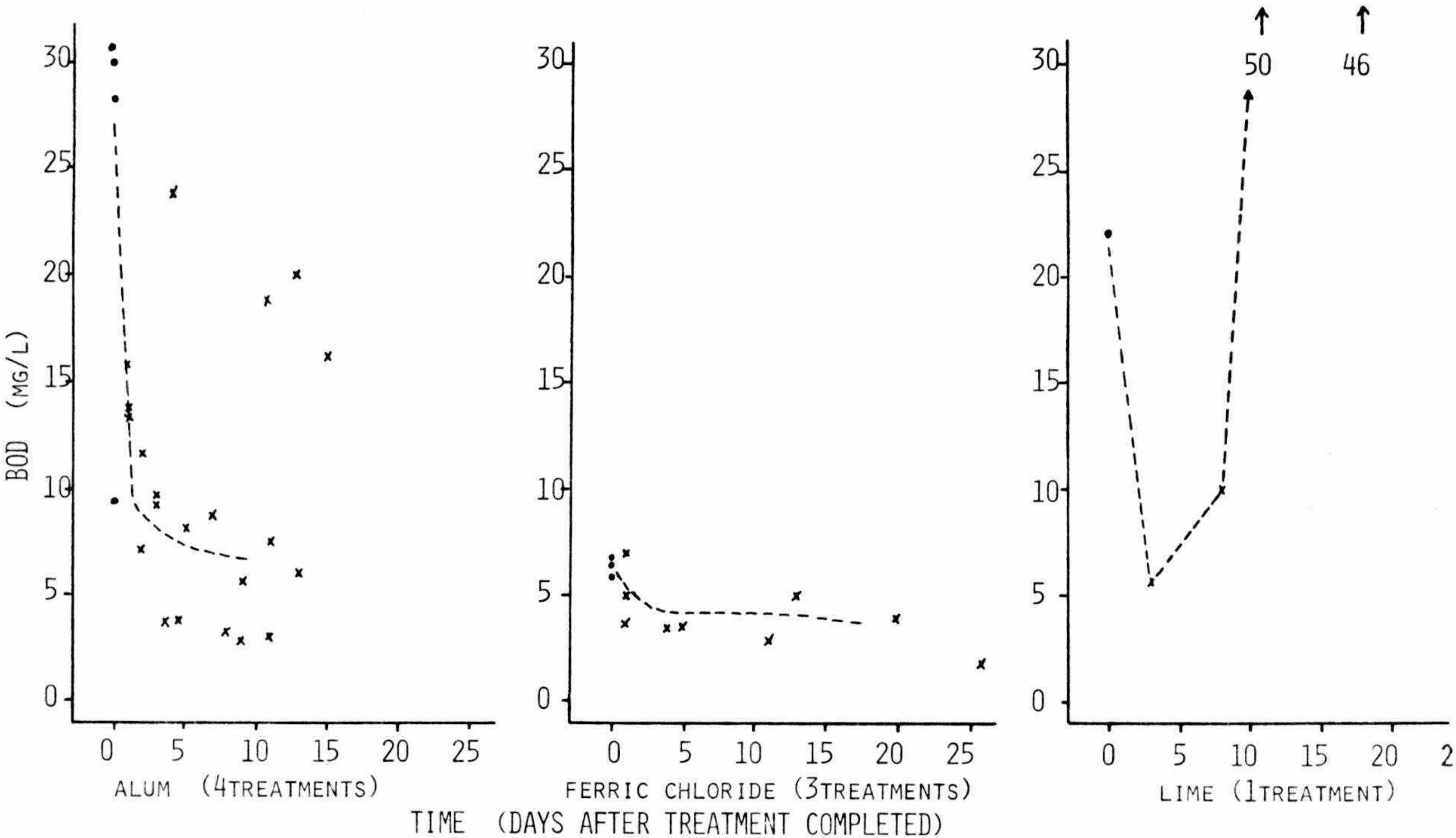


FIGURE 4. RESPONSE OF BOD IN SEASONAL RETENTION LAGOONS BATCH TREATED WITH THREE CHEMICALS

. results before treatment
x results after treatment completed



5) Suspended Solids

The suspended solids in the alum applications ranged from 12.5 to 65 mg/l prior to treatment. The day after treatment the range was usually 5 to 15 mg/l, with only one value above 15 mg/l. These values were maintained or improved over the mean draw-down period.

Pretreatment suspended solids in the three ferric chloride applications ranged from 5-20 mg/l. Only the Geneva Park application exhibited a decrease in suspended solids after treatment (20 mg/l to 15 mg/l).

The lime application exhibited a gradual decline in suspended solids over six days following treatment (25 mg/l to 5 mg/l), after which a rapid increase was noted.

6) pH

The pH was initially reduced by the alum and ferric chloride treatments and increased by the lime treatment.

In the alum treatments there was an initial reduction of less than 1 unit; followed by a gradual increase to pretreatment levels by the tenth day after treatment. The ferric chloride applications displayed a similar decrease in pH, but unlike the alum treatments, the pH drop was still evident ten days after treatment. The pH after treatments with both alum and ferric chloride was not below 6.5.

The lime application caused an increase in the pH of 2.1 units by the first day after the treatment was completed. This was followed by a gradual decrease to day twelve, followed by an increase. During the draw-down, the pH did not fall below 8.7.

7) Bacteria

The range of bacterial results is presented in Table 1. The lower end of the ranges correspond to the higher dosages of chemical and vice versa. Possibly the jar testing method could be developed to include prediction of

disinfection as well as phosphorus removal. Thus by increasing the dosage by some quantity beyond the point necessary for phosphorus removal, disinfection could be effected.

TABLE # 1

TOTAL COLIFORM BACTERIA

	Before Treatment organisms per 100 ml.	After Treatment organisms per 100 ml.
Alum (6 applications)	81,000-120,000	6-108,000 (1)
Ferric Chloride (3 applications)	1,450-10,600	300-3,100
Lime (1 application)	325,000	3,100

(1) Only two applications showed a post-treatment level of greater than 2,500 organisms per 100 ml.

FECAL COLIFORM BACTERIA

	Before Treatment organisms per 100 ml.	After Treatment organisms per 100 ml.
Alum (6 applications)	14,050-22,000	4-6,250 (2)
Ferric Chloride (3 applications)	100-1,200	33-670
Lime (1 application)	15,700	6

(2) Four of the treatments had counts of less than 10 organisms per 100 ml.

8) Cumulative Effects

The alum treatments that have been carried out on the #2 cell at Arthur are listed below.

Date	Dosage in mg/l	Effluent quality on the day after treatment	
		Total phosphorus mg/l	BOD mg/l
November 1971	325*	0.1	---
May 1972	125	0.2	14
October 1972	150	1.1**	16
May 1973	150	0.5	15

* This dosage is a probable overdose. The dosage in the first treatment was ultimately decided on by "in-situ" studies, rather than the jar tests used in subsequent treatments.
** On the next sampling, four days after treatment, the total phosphorus was 0.75 mg/l.

As noted in the table above, the dosages required did not become greater with each treatment as may have been expected if there had been recirculation of the previously precipitated nutrients.

Visual inspection of glass cores taken from the bottom of this cell after the initial alum treatment, exhibited a thin white layer of floc, less than 0.1 inches (0.25 cm) in depth, deposited on the mud bottom. Examination of the bottom with probes after each treatment does not suggest any abnormal sludge build-up.

9) Large Cell Application

The simulation of a large cell application on Arthur #1 cell in May, 1972 produced residual total phosphorus and BOD of 0.1 mg/l and 13 mg/l respectively. A full scale large cell treatment was carried out in May, 1973 at Listowel, but results are not yet available.

10) Field Observations

Water Clarity

The Secchi disc reading in the alum treated lagoons ranged from 7 inches (.2 metres) to 16 inches (.3 metres) prior to treatments. The day following treatment the Secchi disc readings in these lagoons ranged from 48 inches (1.22 metres) to 60 inches (1.52 metres), with four of the six treatments having readings of 60 inches (1.52 metres).

Pretreatment Secchi disc readings in the ferric chloride treatments ranged from 7 inches (.2 metres) to 20 inches (.5 metres). Following treatment the range was 53 inches (1.35 metres) to 60 inches (1.52 metres). A slight orange tinge was visible in the water the day following treatment.

Lime treatment increased the Secchi disc reading from 8 inches (.2 metres) to 35 inches (.9 metres).

Foaming

Foaming at the point of discharge of the effluent was noted in applications with all three chemicals tested.

In discharging the lagoons, the turbulent mixing of the clear effluent in the discharge pipe caused foaming in the manholes along the pipe and also at the point of discharge. There was a build-up of foam in the receiving streams for approximately 100 feet (30.5 metres) below the discharge point. Two hundred yards (182.6 metres) below the

point of discharge this foam had virtually disappeared.

The foam from the Arthur #2 cell alum treatment in 1971 was collected in large plastic bags and returned to the laboratory for analysis. The residue from the foam was characterized as a mixture of synthetic anionic surfactants, the source of which probably was common detergents.

This foaming in the effluent may cause aesthetic problems in isolated instances where the discharge point is in a conspicuous area.

GENERAL CONSIDERATIONS

1) Application

The main objectives in a batch treatment application method are rapid, even distribution of the chemical, combined with mixing action. The outboard motorboat method described above achieves this objective.

The application times for full scale trials of batch treatment are presented below. As the man hours spent in application varies with the quantity of chemical required, these application times are not directly comparable.

	Alum	Lime	Ferric Chloride
Man hours per acre	3	24	13 powder, 2 liquid
Man hours per million gallons	2.4	17.7	9.6 powder, 1.6 liquid
Set up and clean up time-man hours per application	16	125	16

2) <u>Physical Design Requirements</u>

If batch treatment is to be implemented on a regular basis the following facilities are advisable:

1. A roadway to the edge of each cell with a turn-about area sufficient to carry 50 tons (45 metric tons) in early spring and late fall or a piping system to deliver the chemical to each cell.
2. A boat ramp and a small dock installed in each cell.
3. In multiple cell installations separate controllable feed and outlet facilities are necessary to allow diversion of raw sewage during treatment and draw-down.
4. A low level outlet pipe in the lagoon to allow complete drainage of the cell contents.
5. A discharge pipe from the lagoon of sufficient size and design to allow drainage of the treated area over a 5-10 day period.
6. In new large installations a number of medium sized cells of 10-15 acres (4 ha - 6 ha) would be better suited to this type of treatment than one or two large cells. These medium sized cells could be treated individually and drawn down over a relatively short period of time, thus maintaining optimum water quality in the effluent.

3) <u>Jar Tests</u>

The prime criteria used in jar testing is the reduction of total phpsphorus to below 1 mg/l. The procedure outlined above is an adequate method to determine the required dosages to effect phosphorus removal. The total phosphorus levels obtained in full scale trials closely approximated those predicted by the jar tests in the case of lime and

ferric chloride. The use of alum in full scale field trials resulted in slightly better phosphorus removal efficiencies than predicted by the jar tests.

Jar tests should be carried out prior to each application. As noted above there is a considerable variation in chemical requirements at various locations. Also, subsequent treatments of the same cell may require different dosages, if raw sewage characteristics alter appreciably. Cells within one lagoon installation may vary due to size, age, operating procedure etc; thus, the dosage required in one cell may not be adequate for another.

The choice of a chemical chould be based on individual chemical cost analysis as well as application economics analysis.

Jar testing should be carried out by a reputable organization to ensure consistent methods and results.

CONCLUSIONS

Batch chemical treatment of seasonal retention lagoons should be considered as a reasonable alternative to conventional forms of sewage treatment. A high quality effluent may be obtained at a relatively low monetary and manpower input.

Of the three chemicals tested, only the use of alum and ferric chloride can be recommended at this time. A high quality effluent was produced and maintained over the draw down period.

The lime precipitation produced a relatively good initial effluent, although deterioration was rapid. The somewhat lower cost of the chemical was offset by the very high manpower requirement.

REFERENCES

Canada/United States International Agreement on Great Lakes Water Quality, April, 1972.

Hamilton, A. L., 1971. "Eutrophication and the current controversy over its causes and cures", Presented at 22nd annual Western Canada Water and Sewage Conference, Winnipeg, September.

International Joint Commission Report, 1969. "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River", Volume I.

Jernelov, A., 1970. "Phosphate Reduction in Lakes by Precipitation with Aluminum Sulphate", Presented at the 5th International Conference on Water, San Francisco and Hawaii, July.

Lea, W. L., G. A. Rohlich and W. J. Katz, 1954. "Removal of Phosphates from Treated Sewage", Sewage and Industrial Wastes, 26(3): 261-275.

Malhotra, S. K., G. F. Lee and G. A. Rohlich, 1964. "Nutrient Removal from Secondary Effluent by Alum Flocculation and Lime Precipitation", International Journal of Air and Water Pollution, 8: 487-500.

Nilsson, R., 1969. "Phosphate Separation in Sewage Treatment", Process Biochemistry, May, pp. 49-52.

Sawyer, C.N., 1968. "The Need for Nutrient Control", Journal Water Pollution Control Federation, 40: 363-370.

Shapiro, J., 1970. "A Statement on Phosphorus", Journal Water Pollution Control Federation, 42: 772-775.

Vallentyne, J. R., W. E. Johnson and A. J. Harris, 1970. "A Visual Demonstration of the Beneficial Effects of Sewage Treatment for Phosphorus Removal on Particulate Matter Production in Waters of Lakes Erie and Ontario", Journal of the Fisheries Research Board of Canada, 27: 1493-1496.

Vollenweider, R. A., 1968. "Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, With Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication". OECD Report, DAS/CSI/68-27, Paris.

Wall, J. P., J. O. Peterson, T. L. Wirth and S. M. Born, 1971. "Horseshoe Lake: Nutrient Inactivation by Chemical Precipitation". Preliminary Report, University of Wisconsin and Department of Natural Resources.

MECHANICAL AND PROCESS DESIGN

DESIGN CONSIDERATIONS IN THE IMPLEMENTATION OF ONTARIO'S PHOSPHORUS REMOVAL PROGRAMME

by:

B. I. Boyko and J. W. G. Rupke

Ontario Ministry of the Environment

Research Branch

135 St. Clair Avenue, West

Toronto, Ontario

TABLE OF CONTENTS

DESIGN CONSIDERATIONS IN THE IMPLEMENTATION OF ONTARIO'S PHOSPHORUS REMOVAL PROGRAMME

INTRODUCTION

The Province of Ontario is presently involved in a five-year programme to control phosphorus discharges from more than two hundred existing wastewater treatment plants serving some 4.7 million persons. In order to implement this programme, it was necessary to develop methodology that would allow the prediction of prime coagulant best suited for phosphorus removal at any particular treatment facility and to determine whether the chemicals used for phosphorus removal would have any physical or process effects on present wastewater processes, facilities, methods of sludge treatment, and subsequent sludge disposal practices.

A Research programme, funded under the Canada/Ontario Agreement on the Lower Great Lakes, was subsequently undertaken using jar testing techniques as a basis for the predictive aspects of the study; full scale phosphorus removal studies were conducted at wastewater treatment facilities ranging in size from 0.05 to 24.0 mgd (227 to 109,000 cu m/day) capacity.

This report discusses the predictive methodology, operational results, problem areas, and design considerations that have resulted from the full scale studies conducted.

In addition, the results of studies involving phosphorus removal through continuous chemical addition to waste stabilization pond systems are discussed.

BACKGROUND

As a result of a 1969 International Joint Commission report[1] recommending that phosphorus discharges from all sources in the Lower Great Lakes be reduced to the lowest practical level, the Province of Ontario announced a policy requiring the installation of phosphorus removal facilities at municipal and institutional wastewater plants in both the Lower Great Lakes areas and in inland recreational waters.

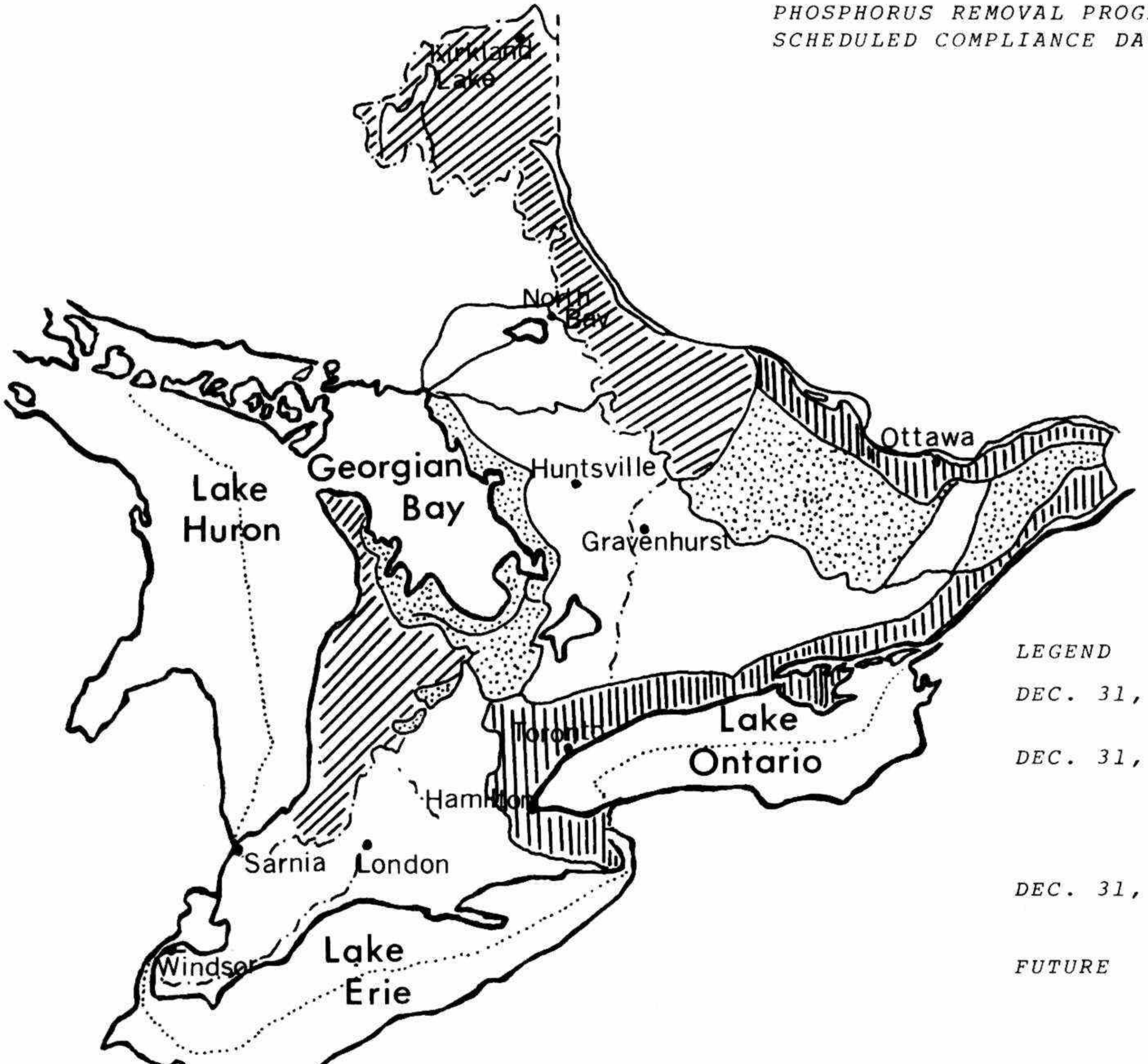
Initially the policy required a minimum removal of 80% of the phosphorus from wastewater plant influents with the need for higher levels of removal to be determined by further studies of the receiving waters. This criterion was subsequently superseded in the Lower Great Lakes by the signing, in April, 1972, of the Canada-United States International Agreement on Great Lakes Water Quality[2] which called for an effluent objective of 1 mg/l total phosphorus.

Permanent phosphorus removal facilities must be operational by December 31, 1973, in the most critically affected areas of the Province, by December 31, 1975, for those discharging to waters deemed to be in a less critical condition, and three years after notification in all other areas of the Province where problems are found to exist. Figure 1 outlines the scheduled phosphorus removal compliance dates for the southern section of the Province of Ontario.

In order to implement and accelerate pollution control programmes, the governments of Canada and Ontario signed an agreement[3] that secured funding for a $250,000,000 capital works programme aimed at upgrading sewage collection systems, treatment works, and including the installation of phosphorus removal equipment. An additional $6,000,000 over the five year term of the agreement was provided for related research studies.

FIGURE 1

PROVINCE OF ONTARIO - SOUTHERN SECTION
PHOSPHORUS REMOVAL PROGRAM
SCHEDULED COMPLIANCE DATES



LEGEND

DEC. 31, 1973	ALL PLANTS
DEC. 31, 1973	PLANTS LARGER THAN 1 mgd OR WHERE LOCAL PROBLEMS DEMONSTRATED
DEC. 31, 1975	PLANTS LARGER THAN 1 mgd
FUTURE	STUDIES REQUIRED TO DETERMINE NEED

Although considerable research effort had gone into technical studies of phosphorus removal at wastewater treatment plants, the studies conducted by the Ministry of the Environment, and funded by the Canada/Ontario Agreement, had the following objectives:

1) Develop methodology that would allow the prediction of what prime coagulant would be best suited for phosphorus removal at a particular WPCP,
2) Determine the effects of phosphorus removal using prime coagulants on the activated sludge process and all its modifications,
3) Provide information on both the quantity and quality of sludge to be expected from WPCP's effecting phosphorus removal,
4) Insure that the present methods of sludge treatment were adequate for chemical-organic sludges,
5) To determine whether phosphorus removal could be readily implemented into existing treatment plants without major capital works expenditures,
6) Provide a method of phosphorus removal in non-mechanical treatment systems, e.g. stabilization ponds and aerated lagoons.

PREDICTIVE METHODOLOGY

(a) Procedure

The use of jar testing procedures to simulate water treatment plant conditions is a well known and often used technique[(4)]. More recently, this same jar test procedure has been used to provide preliminary design information on phosphorus removal by chemical precipitation in municipal wastewater treatment systems. This standard procedure parallels that used by potable water treatment plant operators in that a standard arbitrary timing sequence is used to

ensure adequate mixing in reaction time followed by sufficient details of the jar testing procedures used are available elsewhere[5]. Rather than attempt to duplicate hydraulic and mixing conditions within a particular WPCP being studied, we have found that adopting a standard jar testing technique has yielded satisfactory predictive results.

The preliminary testing is done on both raw sewage and final effluent grab samples using a wide range of primary coagulant dosages. Additional jar tests are subsequently conducted to narrow down the range of coagulant dosage required to effect the required degree of phosphorus removal, expressed either as a percentage removal or a residual phosphorus concentration.

Finally, a number of jar tests are conducted using dosages that attempt to bracket the range of removal efficiency desired, i.e. dosages yielding removals lower, equal to and higher than the objective. It is essential that these jar tests be conducted over an extended period of time in order that a representative variety of sewage characteristics are encountered. Grab samples for jar testing should be taken at different times of the day and on various days of the week. Once the range of chemical dosages has been determined, it is essential not to alter these dosages used in the jar testing in order to avoid deliberately skewing the results. In order to have sufficient data to draw meaningful conclusions, it was considered that a minimum of ten data points should be obtained for each chemical dosage on each waste stream being studied.

(b) Data Analysis

Rather than looking at the average total phosphorus removal for each set of data, more meaningful information is obtained by plotting each set of data points on arithmetic probability paper; this allows a direct comparison of the various chemical dosages used.

Such probability curves have two significant aspects:

1) The relative vertical position indicates the degree of effectiveness of the coagulant used at that given dosage,
2) The slope of the line indicates the expected reliability of phosphorus removal using that particular coagulant.

A typical set of data using alum as the coagulant on raw sewage is shown in Figure 2.

Using similar curves for each coagulant, the dosage requirements to yield a given degree of phosphorus removal (or residual phosphorus value), for a specified frequency, may be determined.

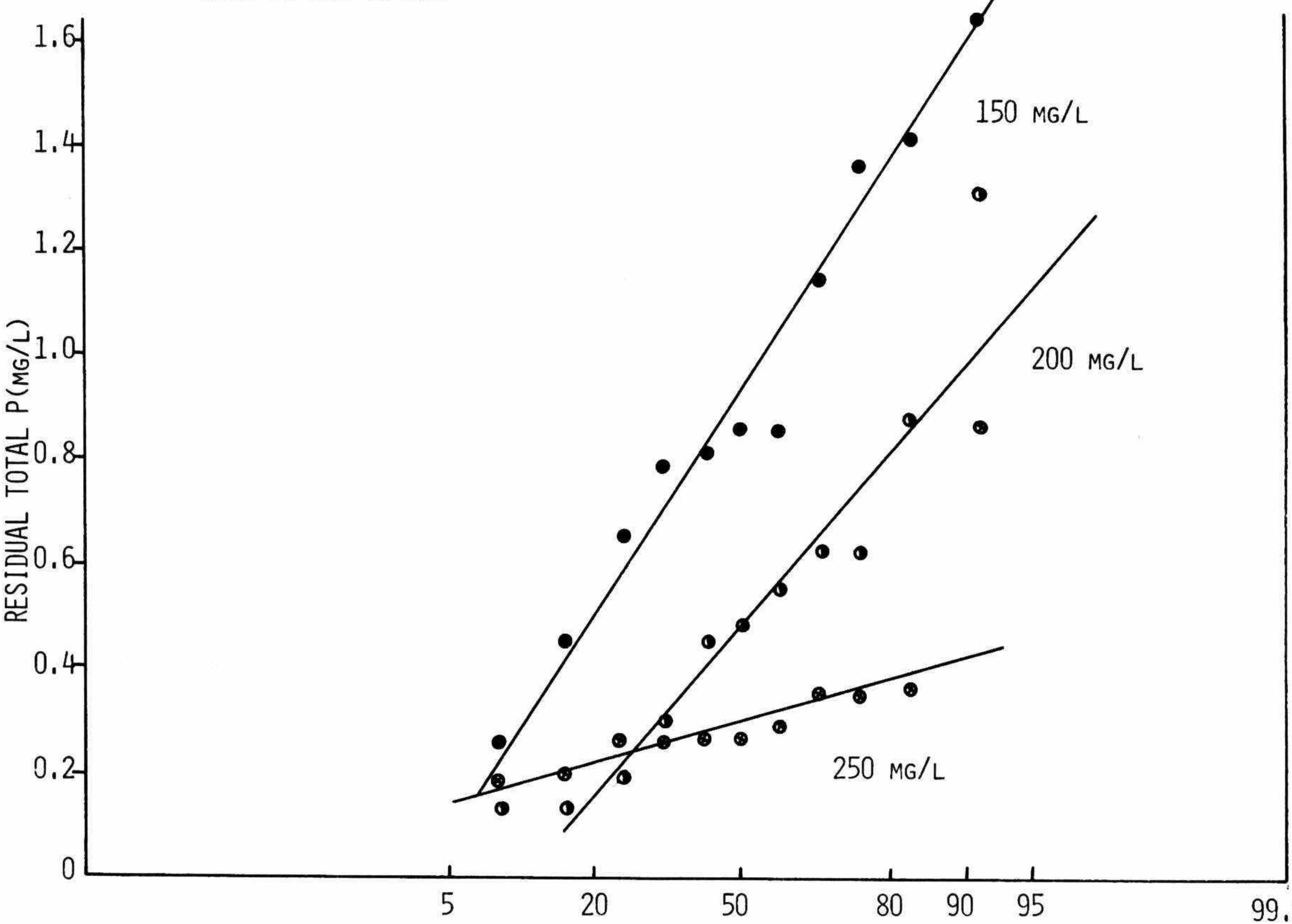
The relative economics of the chemical processes for total phosphorus removal can then be determined on the basis of optimum dosage, delivered cost, and availability of chemical.

(c) Results and Discussion

Graphical interpretation of the jar test data accumulated from many of the WPCP's tested to date is shown in Figures 3 - 7. Each figure represents the overall study results obtained using a particular coagulant on raw sewage (Figures 3 - 5) or on final effluent (Figures 6 - 7).

Each of the data points used in the regression analysis and confidence limit determination represents the complete result of the jar test study conducted at a

FIGURE 2 JAR TEST RESULTS
ALUM ON RAW SEWAGE



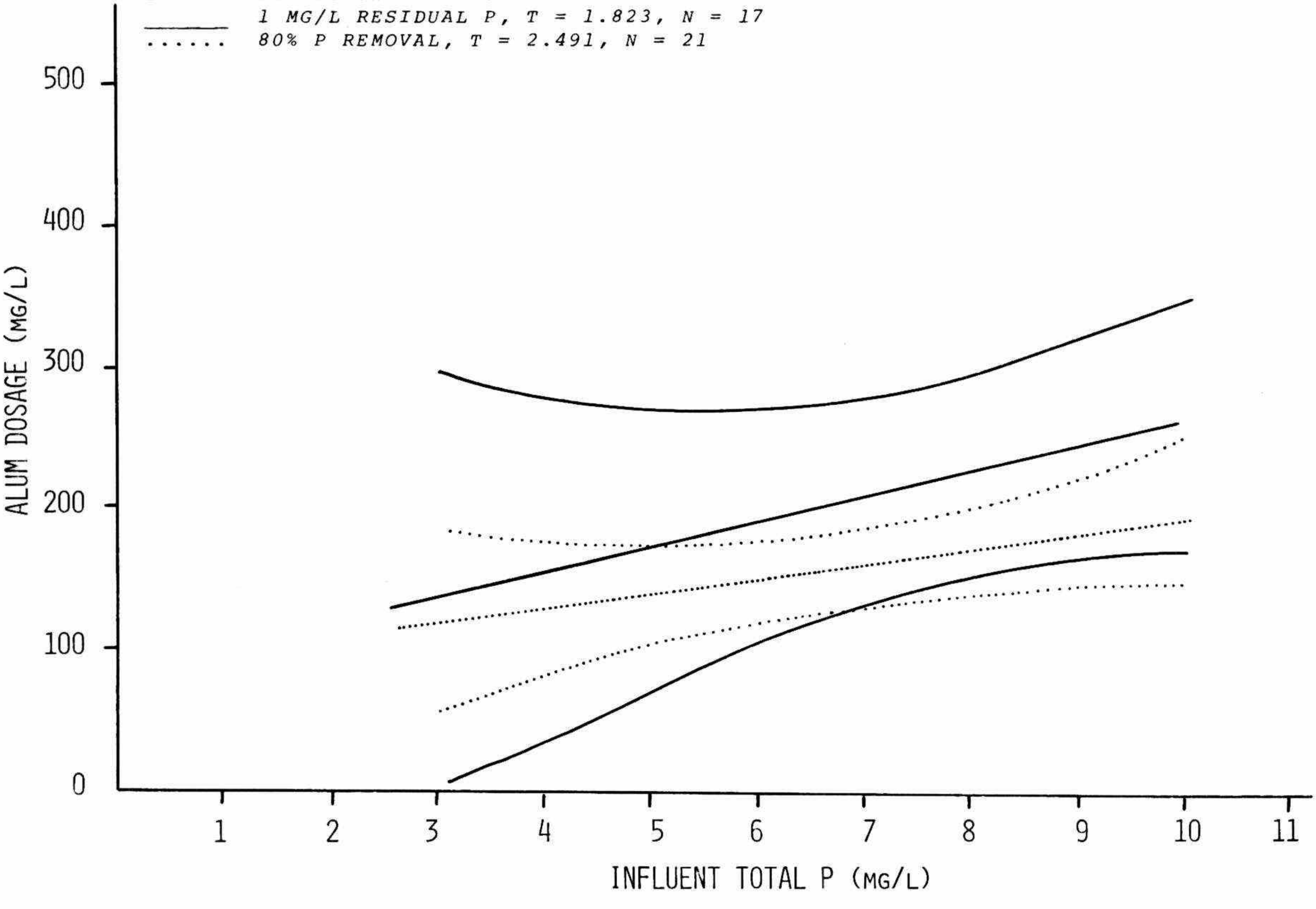
particular WPCP and not an individual jar test result.

Since it has been previously speculated that coagulant demand to effect a specific phosphorus removal is a function of influent phosphorus concentration, Figures 3 - 7 are presented as coagulant dosage plotted against influent phosphorus concentration. Where jar tests were conducted on final effluent, the coagulant requirement is plotted against final effluent total phosphorus concentration.

From Figures 3, 4 and 5, all involving addition of prime coagulant to raw sewage, it can be seen that higher dosages are required to effect a 1 mg/l residual total phosphorus rather than 80% reduction of raw sewage total phosphorus. Although the significance of correlations can be determined from the given t values, the wide 95% confidence band indicates that such a correlation, where it exists, is of little value for either predictive or control purposes. Figure 5 illustrates that in order to effect 80% removal of raw sewage phosphorus, the required lime dosage increases with decreasing raw sewage phosphorus concentrations. This apparent anomaly can be explained in that as raw sewage phosphorus concentrations diminish, the residual phosphorus value also decreases with an 80% removal requirement. With lime being used for phosphorus removal, lower residual P values necessitate higher influent pH values thereby increasing the required lime dosage.

In Figures 6 and 7, the chemical requirements to effect phosphorus removal using alum and ferric chloride on final effluent are shown. Studies conducted in the early part of this programme indicated that jar tests done on final effluent gave similar results to those conducted on mixed liquor; this then allowed the use of final effluent for jar testing that would yield predictive results with respect to the application of coagulant into mixed liquor. This preliminary testing procedure does not take into account

FIGURE 3: P REMOVAL IN RAW SEWAGE
ALUM DOSAGE VS TOTAL PHOSPHORUS
LINEAR REGRESSION & 95% CONFIDENCE BAND



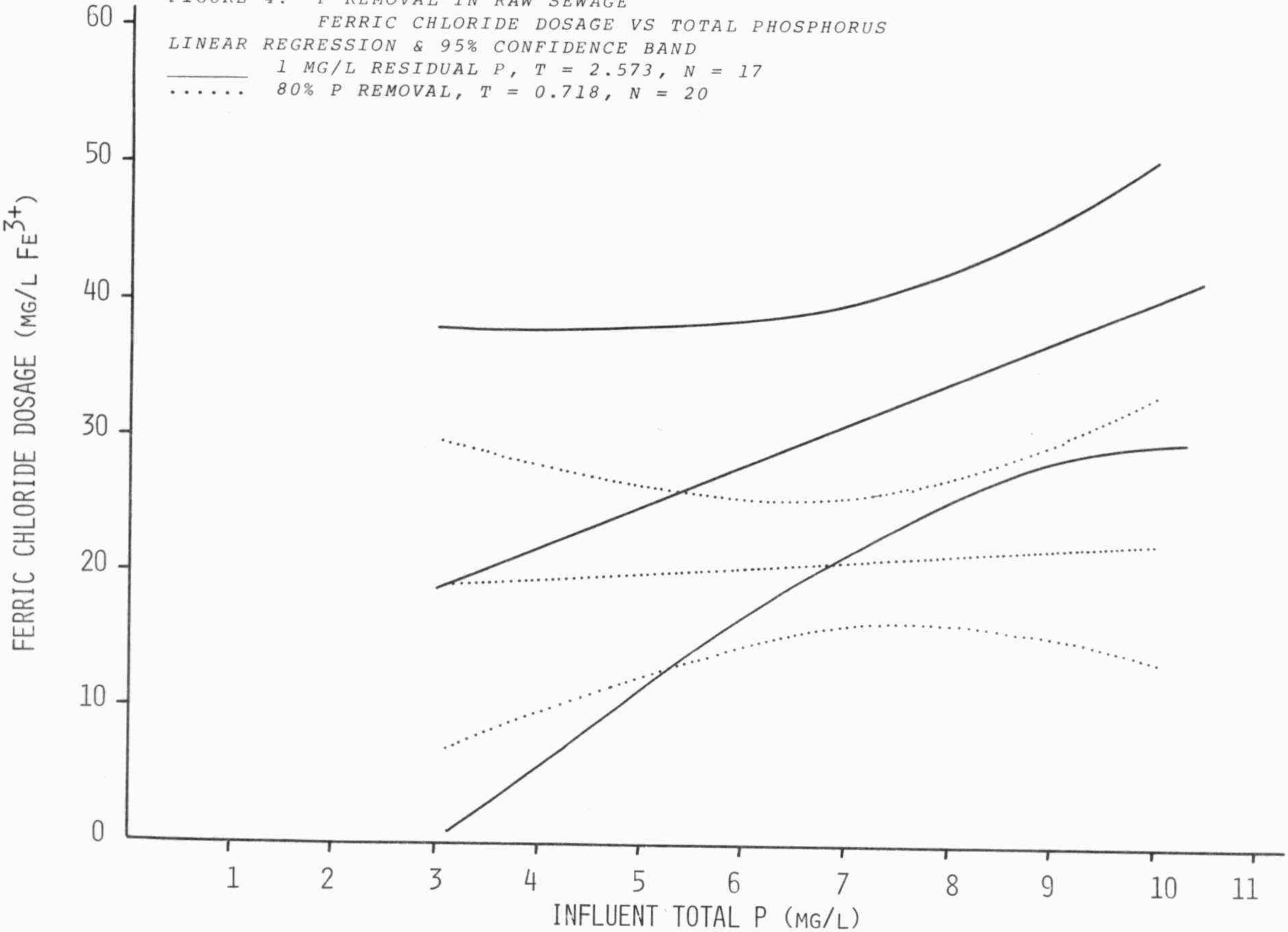


FIGURE 4: P REMOVAL IN RAW SEWAGE
FERRIC CHLORIDE DOSAGE VS TOTAL PHOSPHORUS
LINEAR REGRESSION & 95% CONFIDENCE BAND

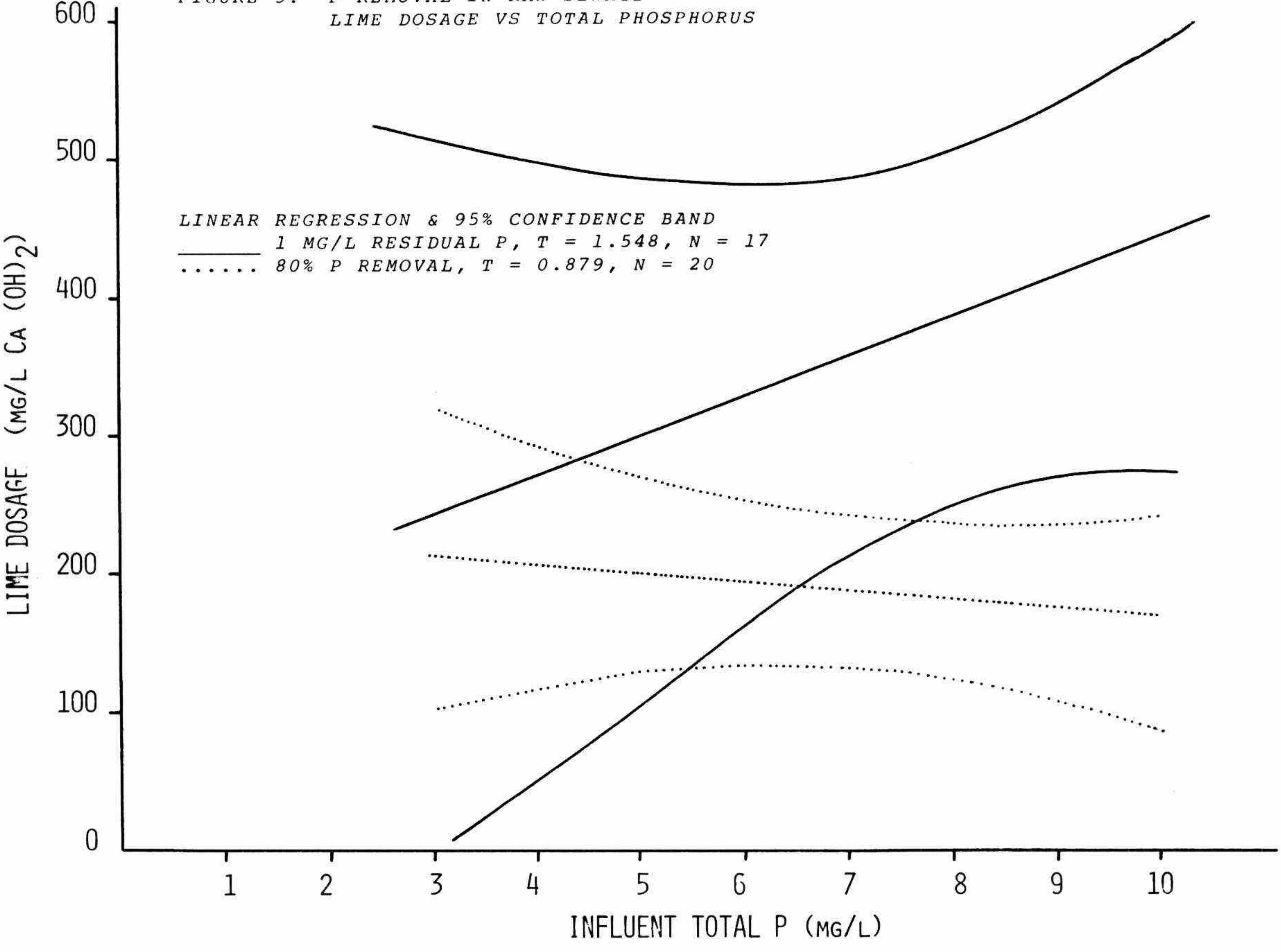


FIGURE 5: P REMOVAL IN RAW SEWAGE LIME DOSAGE VS TOTAL PHOSPHORUS

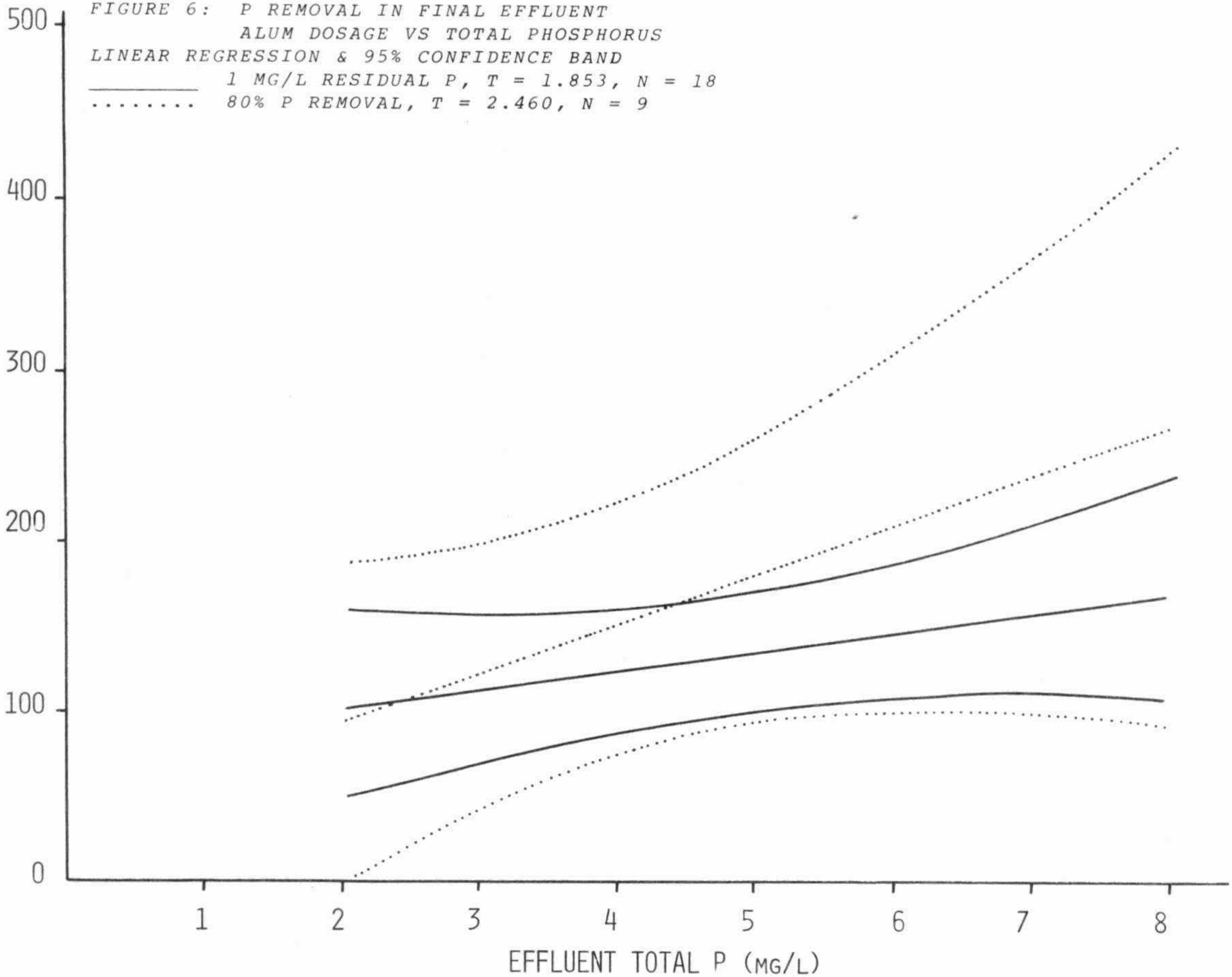


FIGURE 6: P REMOVAL IN FINAL EFFLUENT
ALUM DOSAGE VS TOTAL PHOSPHORUS
LINEAR REGRESSION & 95% CONFIDENCE BAND
———— 1 MG/L RESIDUAL P, T = 1.853, N = 18
.... 80% P REMOVAL, T = 2.460, N = 9

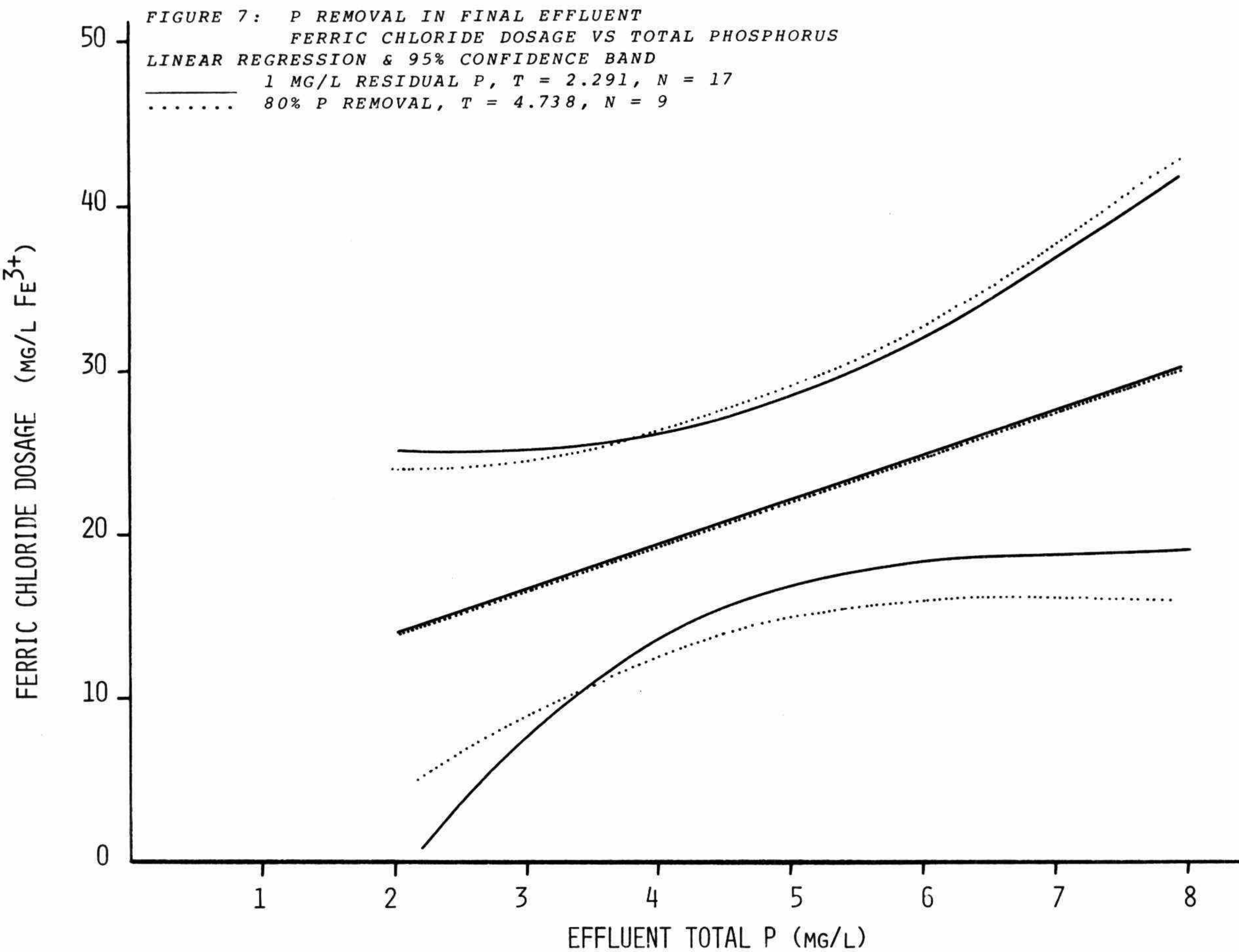


FIGURE 7: P REMOVAL IN FINAL EFFLUENT
FERRIC CHLORIDE DOSAGE VS TOTAL PHOSPHORUS
LINEAR REGRESSION & 95% CONFIDENCE BAND
1 MG/L RESIDUAL P, T = 2.291, N = 17
80% P REMOVAL, T = 4.738, N = 9
FERRIC CHLORIDE DOSAGE (MG/L FE3+)
EFFLUENT TOTAL P (MG/L)
0
10
20
30
40
50
1
2
3
4
5
6
7
8

the effects of accumulated coagulant within the mixed liquor.

Figures 6 and 7 indicate that in general a reduced coagulant dosage is required to effect phosphorus removal in the aeration tank when compared to the addition of chemical to raw sewage.

The analysis of the raw jar test data indicates that the average total phosphorus in raw sewage for the plants studied is 8.0 mg/l with the range being 2.3 - 18.0 mg/l. In final effluent the total phosphorus concentration is 4.4 mg/l with the observed range being 1.1 - 7.7 mg/l.

When considering the variability of the jar tests probability plots, the only generalized conclusion that can be drawn from the data analysed is that municipal sewage with a high industrial waste fraction tends to yield more variable performance with respect to phosphorus removal. The variability of performance as indicated by the slope on the probability plots may aid in selecting which of two chemicals providing phosphorus removal at equal costs are to be used for full scale phosphorus removal.

With respect to analysis of jar test data from a specific plant, Figure 8 indicates chemical dosage requirement as a function of raw sewage total phosphorus concentration. The regressions and broad confidence bands shown are typical of jar test results obtained at many municipalities in that the correlation of dosage and initial phosphorus level is poor and not suitable for chemical addition control purposes. Possibly a feedback chemical dosage control system would be feasible based on effluent total phosphorus concentration rather than the feed forward control system based on influent raw sewage phosphorus level.

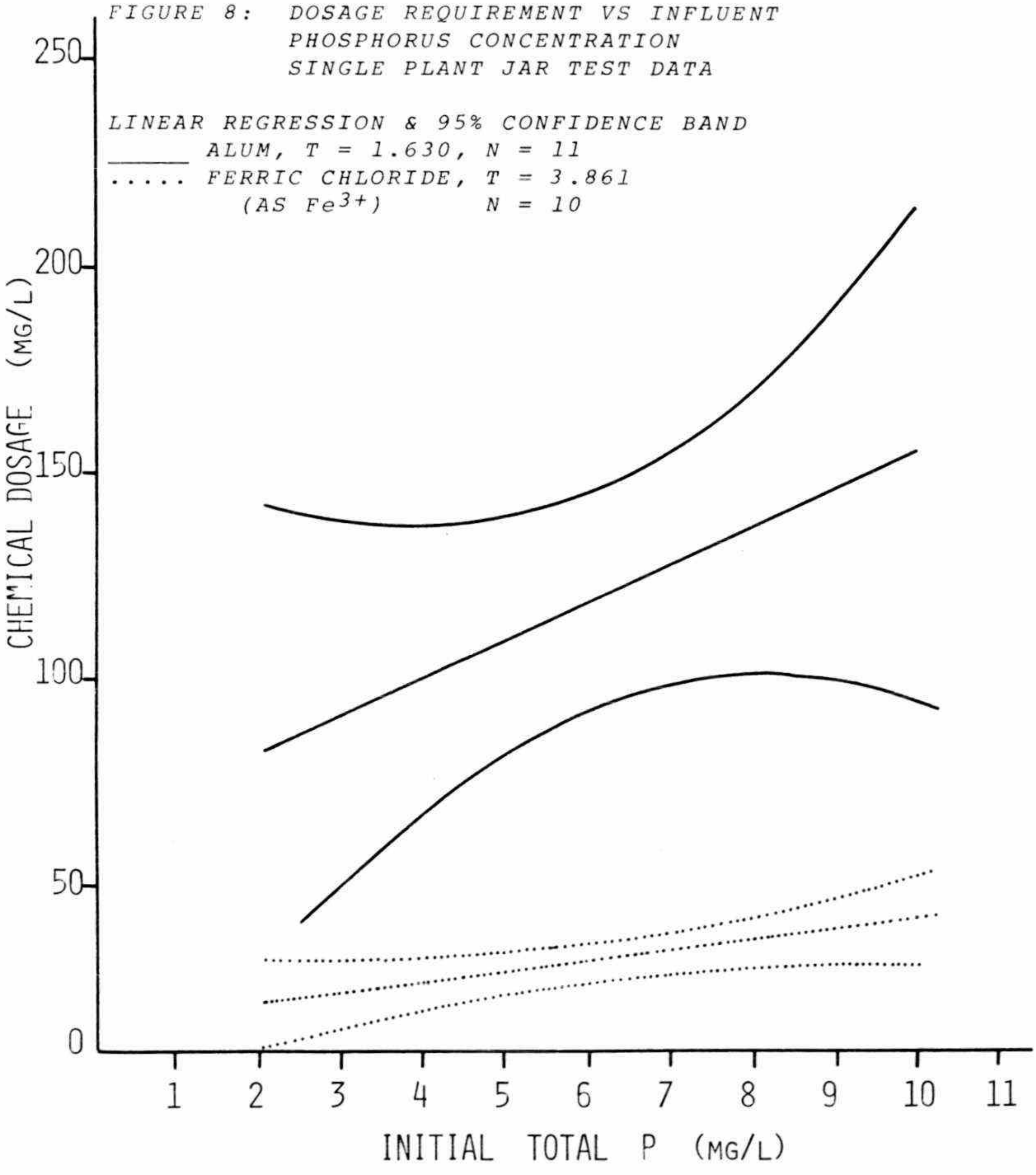


FIGURE 8: DOSAGE REQUIREMENT VS INFLUENT PHOSPHORUS CONCENTRATION SINGLE PLANT JAR TEST DATA

FULL SCALE STUDIES

(a) Research Studies on Mechanical Plants

In order to provide the necessary technical and design information for phosphorus removal implementation, a number of full scale studies were conducted involving the application of the three basic prime coagulants, lime, alum and ferric chloride, in different types of wastewater treatment facilities commonly encountered in the Province of Ontario. Table I summarizes the research studies conducted by outlining the type of wastewater treatment facility, chemical used, point of application, and any additional specific reasons for conducting that particular study.

In order to confirm that the proposed study would be successful at the particular WPCP chosen, preliminary jar tests were conducted according to the method previously outlined. The duration of these full scale studies depend to a great extent on the specific purpose of the study, i.e. where anaerobic digestion was concerned, the studies were of a minimum six months duration, while an activated sludge process would only be of two or three months duration.

Although much of the earlier work was conducted using swimming pools as temporary storage tanks, the incidence of problems using such temporary facilities was quite high and subsequently five thousand gallon chemical storage FRP tanks were used for these temporary studies. Liquid coagulant was fed through chemical feed pumps either proportional to raw sewage flow or manually adjusted according to diurnal flow variations. During these studies various in-plant streams were normally sampled three times a week; where digestion studies were involved, sludge samples were obtained on a weekly basis. In addition, the normal operational parameters of both the activated sludge process and anaerobic digestion process were monitored for the duration of the studies.

TABLE 1

FULL SCALE PHOSPHORUS REMOVAL STUDIES OF MECHANICAL PLANTS

	Type & Size mgd *	Chemical	Point of Addition	Additional Purpose of Study
A)	Conv Act Sl (3.0)	alum	Raw Aeration	Anaerobic digestion
B)	Conv Act Sl (4.0)	alum	Raw	Vacuum filter
C)	Conv Act Sl (4.0)	alum	Raw Aeration	Low alkalinity raw water
D)	Conv Act Sl (0.75)	alum	Aeration	Anaerobic digestion
E)	Conv Act Sl (2.0)	lime	Raw	Anaerobic digestion
F)	Conv Act Sl (0.2)	lime	Raw	High calcium raw water
G)	Conv Act Sl (4.0)	lime	Raw	Vacuum filter
H)	Conv Act Sl (6.4)	ferric chloride	Raw Aeration	
I)	Conv Act Sl (4.5)	ferrous sulphate	Raw	Waste pickle liquor, anaerobic digestion
J)	Cont Stab (0.54)	alum ferric chloride	Contact zone Contact zone	Aerobic digestion
K)	Ox Ditch (0.72)	alum ferric chloride	Raw Raw	Mixing considerations
L)	Primary (8.0)	ferric chloride	Raw	Anaerobic digestion
M)	Primary (24.0)	alum	Raw	Vacuum filter
N)	Ext Aer (0.05)	alum ferrous chloride	Raw Raw	

* X 4550 cu m/day

(b) Research Studies on Non-mechanical Plants

In order to allow for complete implementation of the phosphorus removal programme, research studies were conducted to determine a means of achieving phosphorus removal in aerated lagoons and conventional stabilization ponds. Table II outlines some of the research studies conducted on such non-mechanical wastewater treatment facilities.

For the study involving phosphorus removal at a facultative aerated lagoon facility, liquid alum fed to the raw sewage at a nearby pumping station, was used for the initial phase of the study, followed by an attempt to effect phosphorus removal using lime, again fed to the raw sewage at the pumping station. In addition to liquid phase samples, close surveillance was made of the depth of sludge in the aeration basins.

Presently phosphorus removal studies at three conventional waste stabilization pond systems are continuing. These involve the addition of liquid alum, lime and ferric chloride to the raw sewage prior to entering the stabilization ponds. It is expected that these studies will be of approximately two years duration. Raw sewage and stabilization pond contents are sampled weekly and analysed for routine chemical parameters including algal enumeration.

TABLE II

FULL SCALE PHOSPHORUS REMOVAL STUDIES AT NON-MECHANICAL PLANTS

Type	Size of cell treated *(acres)	Chemical	Point of Addition
Facultative Aerated Lagoon	0.6	Lime Alum	Pumping Station Pumping Station
Conv Stab Lagoon	13.2	Alum	Pumping Station
Conv Stab Lagoon	15	Lime	Mix tank prior to entering lagoon
Conv Stab Lagoon	16	Ferric chloride	Pumping Station

* X 0.405 = ha

RESULTS AND DISCUSSION

(a) Studies on Mechanical Plants

The effluent quality results from the studies carried out in mechanical plants are summarized in Table III.

(i) Primary Performance

In primary plants the addition of chemical precipitants significantly improves the solids capture of the system. This improvement is somewhat better when using metal salts than when using lime for phosphorus removal. Table III shows that in plants adding metal salts (L & M) the observed effluent quality would be 1.0 mg/l total P, 35 mg/l BOD and 30 mg/l SS. Data available from two primary plants operating with lime addition have shown that the observed effluent quality using lime as the precipitant is 1.3 mg/l Phosphorus, 40 mg/l BOD and 50 mg/l SS at lime dosages of 200 - 225 mg/l as $Ca(OH)_2$.

(ii) Process Performance of Activated Sludge Systems

In the conventional activated sludge system (A through I), the effluent BOD and SS values were similar to those normally associated with this type of treatment system. The total phosphorus reduction was near that predicted by the jar testing programme at most of the plants. In some cases (A, D, and I), the dosage required to meet the objectives was somewhat lower than that predicted. The presence of industrial wastes in appreciable quantity had a severe detrimental effect on the ability of prime coagulant to remove phosphorus. This problem was particularly pronounced when phosphorus removal was effected across the primary clarifier rather than the aeration section. All studies at municipalities receiving significant industrial waste loadings encountered this situation.

In all activated sludge systems where chemical addition to the aeration tank discharge was used to precipitate phosphorus, the hydraulic load on the final clarifier

TABLE III

SUMMARY OF RESULTS IN MECHANICAL PLANTS

Plant No.	Chemical & Predicted Dosage (mg/l)	Actual Dosage (mg/l)	Point of Application	Effluent Quality: Total P mg/l	Total P % Rem.	Ortho P mg/l	BOD mg/l	BOD % Rem.	SS mg/l
A	Alum (200)	200	Raw	0.5	96	0.4	7	98	15
		150	Raw	1.2	88	0.8	5	99	15
		100	Raw	1.8	80	1.25	8	98	12
		100	Aeration	1.7	98	0.6	16	97	19
		75	Aeration	2.6	92	0.8	23	96	32
B	Alum (150)	150	Raw	1.2	88	1.0	25	81	11
C	Alum (125)	125	Raw	1.6	84	0.2	22	88	40
		125	Aeration	1.7	78	0.1	37	82	56
		175	Aeration	0.5	93	0.1	36	81	23
D	Alum (175)	131	Aeration	1.3	88	0.4	22	92	24
E	Lime (-)	200	Raw	2.0	80	1.8	9	96	7
F	Lime (70)	130	Raw	3.1	45	2.2	6	91	13
G	Lime (150)	125	Raw	1.8	80	1.6	31	73	6
H	Ferric Chloride ($10\ Fe^{3+}$)	$10Fe^{3+}$	Raw	0.8	88	0.3	15	87	6
		$10Fe^{3+}$	Aeration	1.3	80	0.7	15	86	9
I	Ferrous sulphate ($40\ Fe^{2+}$)	$20Fe^{2+}$	Raw	3.0	83	2.1	21	88	13
J	Alum (125)	125	Contact zone	0.3	94	0.1	3	90	7
	Ferric Chloride ($15\ Fe^{3+}$)	$15Fe^{3+}$	Contact zone	0.9	88	0.5	9	94	14

TABLE III - continued

SUMMARY OF RESULTS IN MECHANICAL PLANTS

Plant No.	Chemical & Predicted Dosage (mg/l)	Actual Dosage (mg/l)	Point of Application	Effluent Quality					
				Total P		Ortho P	BOD		SS
				mg/l	% Rem.	mg/l	mg/l	% Rem.	mg/l
K	Alum (125)	125	Raw	1.0	80	.2	17	63	37
	Ferric Chloride (15 Fe^{3+})	15Fe^{3+}	Raw	0.8	83	.5	6	91	11
L	Ferric Chloride (15 Fe^{3+})	15Fe^{3+}	Raw	1.2	78	0.5	39	61	33
		15Fe^{3+} & 0.5 A-23	Raw	1.3	77	0.7	34	68	26
		20Fe^{3+}	Raw	0.7	85	0.1	37	62	28
		20Fe^{3+} & 0.5 A-23	Raw	0.8	88	0.2	33	67	17
M	Alum (100)	100 & 0.4 A-23	Raw	0.5	93	0.1	34	72	20
		90 & 0.4 A-23	Raw	1.0	87	0.4	42	61	30
N	Alum (-)	230	Raw	1.5	91	-	14	91	55
	Ferrous Sulphate (-)	12.5Fe^{2+}	Raw	4.1	68	-	16	89	40
		15 Fe^{2+}	Raw	2.6	86	-	12	94	32

had a marked effect on effluent quality. At hydraulic loads above 650 - 700 gpd/sq ft (31.4 - 33.8 cu m/sq m/day), a steady deterioration in effluent quality occurred. Final effluent SS values of 25 mg/l were consistently obtained when the hydraulic rate on the clarifiers increased to 800 gpd/sq ft (38.7 cu m/sq m/day). Below 650 gpd/sq ft (31.4 cu m/sq m/day) there appears to be no further decrease in effluent SS values. The minimum expected SS value is 10 mg/l from these systems. The effluent BOD values were observed to follow the fluctuations of the effluent SS very closely. With satisfactory solids separation, BOD values of 10 - 15 mg/l were consistently obtained in the studies.

In the operation of full scale plant studies within existing structures, phosphorus removal was readily effected providing adequate mixing of the chemical stream and the wastewater was obtained. In cases where the initial results from the full scale plant study did not approach the jar test predicted results, it was found that either inadequate mixing or excessive hydraulics were the cause. Efficient mixing was obtained in full scale plants in the following ways:

a) chemical injection into the suction side of raw sewage pumps
b) chemical addition into a preaeration tank provided significantly more air can be supplied at the addition point
c) chemical addition at a parshall flume or similar constriction in a flow channel
d) chemical addition into the channel or pipe between the aeration tank and the final clarifier provided adequate mixing is already available or additional mechanical agitation or air mixing is provided.

In several cases, the P removal efficiency was doubled by increasing the mixing intensity at the point of

chemical addition. The reaction times available in existing plants have normally proven to be adequate. It was found that by matching the chemical feed rate to the incoming hydraulic load three to eight times/day, adequately consistent results were obtained. No benefit of matching the chemical feed rate to the incoming phosphorus load has been observed.

In plant C, where the effect of alum addition to a sewage from a municipality with a low alkalinity raw water was studied, it was found that at acceptable hydraulic rates, alum dosages up to 125 mg/l did not adversely depress the pH. However, at alum dosages of 175 mg/l, the pH was depressed to as low as 3.0 at times. The raw water supply to this municipality has an alkalinity of 10 mg/l as $CaCO_3$ and the raw sewage alkalinity averaged 150 mg/l as $CaCO_3$.

In plant F, jar tests predicted that the addition of 70 mg/l lime to the raw sewage would effect P removal to the desired 1 mg/l. This sewage is unique since it contains a great deal of alkalinity (300 mg/l as $CaCO_3$), and total hardness (950 mg/l as $CaCO_3$). The full scale study was started at the 70 mg/l lime level, but inadequate P removal was experienced. An increase in dosage to 120 mg/l lime did not significantly improve the removal efficiency. Based on raw sewage titration curves, it is anticipated that dosages up to 225 mg/l may be required to effect P removal.

The use of waste pickle liquor in plant I yielded significantly better results than those predicted by jar tests. The addition of 20 mg/l Fe^{2+} effected in excess of 80% of total P removal. No deterioration in effluent quality was noted; however, a gradual increase in digested sludge heavy metal content has been observed, although there have been no digester operating problems during the ten months of the study.

In the contact stabilization study, high quality effluent was consistently obtained. No change in aerobic digester operation was noted.

Satisfactory effluent quality and no solids deposition within the ditch resulted from the addition of alum or ferric chloride to the oxidation ditch wastewater treatment plant.

The use of alum and ferrous chloride in an extended aeration plant produced a poor effluent quality. The high effluent SS values are attributable to the addition of the chemicals to the raw sewage. It is anticipated that significantly better operation could be attained by adding the chemicals to the discharge of the aeration tanks.

In plants E, F, and G, the ortho phosphorus level consistently increased from the primary effluent to the final effluent. This increase is likely due to a resolubilization of lime floc carried into the neutral pH regime of the aeration tank. Because of this resolubilization, it is very difficult to obtain a 1.0 mg/l total P residual in the final effluent. When working within existing plants, without major capital addition, it is likely that lime will provide a 1.5 - 2.0 mg/l total phosphorus effluent. To attain higher quality effluents, major capital expenditures may be required.

In plant G, and in other activated sludge plants using lime addition to the raw sewage, it was observed that when influent BOD levels were low or the BOD removal in the primary clarifier was high, both resulting in a primary effluent BOD of less than 50 mg/l, the activated sludge system did not have sufficient buffering capacity to neutralize the high primary effluent pH. In several cases, the aeration tank pH rose to 9.5 - 10 resulting in a severe inhibition of the biological process. Care must be taken to insure adequate BOD loading to the aeration section thus providing

adequate buffering, when using lime addition to the raw sewage.

(iii) Sludge production

In phosphorus removal studies to date, the sludge production and characterization has produced relatively consistent results.

a. Metal Salts

In secondary plants utilizing metal salts, the pounds dry solids produced per MG (kg/cu m) of waste treated has generally increased by 5 - 25%. The production rate during P removal varied from 2000 - 3300 lb dry solids/MG (0.2 - 0.3 kg dry solids/cu m) treated. In addition to this increase in sludge mass, there is a decrease in solids concentration in the raw sludge, dropping the total solids content to 3.5 - 5.0% from the normal 4.0 - 5.5%. The combination of these two effects both tending to increase the net wet sludge volume by approximately 35% and has resulted in several digester operating problems discussed in the next section.

In primary plants, the sludge production increases more drastically as a result of the increased solids capture. A 100% increase in lb solids produced/MG (kg/cu m) can be expected. Depending upon the raw waste characteristics, the solids production varied from 1500 - 2500 lb solids/MG (0.15 - 0.25 kg/cu m) with phosphorus removal from a normal 700 - 1200 lb/MG (0.07 - 0.12 kg/cu m). The majority of this increased production can be attributed directly to the increase in solids capture. A 20% reduction in sludge solids concentration can be expected. The net effect on sludge volume is a 150% increase.

b. Lime

The use of lime for phosphorus removal in secondary plants has produced several very marked changes in both sludge characteristics and sludge production. The sludge production increased from 1800 lb/MG (0.18 kg/cu m)

to 4600 lb/MG (0.46 kg/cu m) with the addition of 200 mg/l lime, while the solids content of the sludge increased from a normal 4.5% to 9%. The net effect was a 25% increase in sludge volume to be handled.

With lime addition at a primary plant, the effects were even more dramatic. The sludge production increased from a normal of 800 lb/MG (0.08 kg/cu m) to 2400 lb/MG (0.24 kg/cu m). The solids concentration increased to 15% from the norm of 7%. The net effect was a 50% increase in sludge volume.

(iv) Sludge digestion and dewatering

Because of the predominance of anaerobic digestion systems in the Province of Ontario, emphasis was placed on assessing the impact of phosphorus removal on this particular sludge treatment process rather than heat treatment or incineration. Table IV summarizes the steady state data collected from the digestion studies.

In all cases where metallic salts were used to precipitate phosphorus, normal digestion operation was observed. Some of the problems experienced during these studies were inadequate heat exchanger capacity due to increased digester hydraulic loading and high gas production rates resulting in inadequate gas-liquid separation and foaming in the primary digester.

These problems did not arise as a direct result of chemical addition but were compounded by the increased volatile solids load on the digestion system. No inhibitive effect of the accumulated metal salts was observed in any of the digesters studied, nor was a significant portion of the phosphorus resolubilized during the digestion process. Even the digester treating phosphate sludge from precipitation with the ferrous sulphate waste pickle liquor showed only 8.0 mg/l ortho P in the digester contents.

TABLE IV

ANAEROBIC DIGESTION OF CHEMICAL SLUDGES

PLANT:	L	A	D	E
Raw Sludge				
% solids	4.4	3.8	7.5	10
% volatile solids	54.5	66	43	27
Digested Sludge				
% solids	16	3	5.9	8
% volatile solids	39.4	54	37.6	25
ortho P (mg/l)	1.9	0.5 - 19	6 - 19.9	4
Supernatant				
% solids	0.17	NA	5.6	1.2
pH range	6.8 - 7.0	NA	7 - 7.3	7.5 - 8.0
Gas production (cu ft/day) (x0.028 = cu m/day)	NA	32,800	8,029	NA
% Reduction of Vol. Solids	45	39.5	18	19
Primary Digester Loading ($lb\ vol/ft^3/d$) (x16.0 = kg/cu m/day)	0.04	0.1	0.054	0.108
Overall Digester Loading ($lb\ vol/ft^3/d$) (x16.0 = kg/cu m/day)	0.03	0.04	0.054	0.05
Gas Analysis	good burning	30% CO_2 70% methane	35% CO_2 65% methane	24% CO_2 76% methane

The digester treating sludge resulting from precipitation using lime in raw sewage encountered several operational problems early in the research study. Erratic lime dosing resulting in periodic massive doses of high pH sludge being pumped to the digester caused the digester pH to rise drastically. After three months of operation, gas production ceased and the cover had to be opened to allow sludge removal. Subsequent studies have shown that if the raw sludge is held for an extended period in the primary clarifier, it will partially neutralize itself to approximately pH 8.0 allowing proper operation of the anaerobic digester system. Table IV shows normal operation which has now been maintained for twelve months[6]. The only significant change from normal operation is the high solids content of the digested sludge.

Table V summarizes the operational results of the use of full scale vacuum filters for the dewatering of raw undigested chemical sludges from both a primary and a secondary plant[7, 8].

A significant increase in conditioning costs was experienced with alum addition to the primary plant. A decrease in cake solids content and filter yield was also noted.

In the secondary plant, little change took place upon alum addition. The addition of lime resulted in a reduction in conditioning costs and an increase in filter yield and sludge cake solids.

Raw lime sludge from a conventional secondary plant using lime coagulation of the raw sewage was dewatered by using a continuous solid bowl conveyor-type centrifuge[9]. In excess of 95% solids capture was obtained using less than 1.0 lb Anionic polymer/ton of dry solids (0.5 gm/kg dry solids); sludge cake solids of 25 - 30% by weight were obtained when treating 5% TS sludge. Centrate solids of

TABLE V

VACUUM FILTRATION OF CHEMICAL SLUDGES

(normal operation in brackets)

Plant (Table I)	G	B	M
Type of Sludge	Lime	Alum	Alum
Filter Yield lb solids/sq ft/hr (x4.882 = kg/sq m/hr)	7.2 (5.2)	4.6 (5.2)	5.8 (11.3)
Conditioning chemicals			
% lime	9.9 (15)	17.9 (15)	27.9 (6.9)
% $FeCL_3$	4.3 (4.5)	5.4 (4.5)	1.1 (1.1)
Costs $/ton (x0.0011 = $/kg)	11.14 (16.08)	17.96 (16.08)	9.50 (3.10)
Cake % dry solids	29	15.9	19.2 (31.1)
Filtrate SS mg/l	-	9630	6810 (2660)

less than 1000 mg/l were consistently obtained. Centrifugation without polymer addition resulted in lower solids capture at simlar cake and centrate solids levels.

(b) Studies on Non-mechanical Plants

The phosphorus removal study on the facultative aerated lagoon facility was unsuccessful. Total phosphorus removals averaged only 45% with an effluent total phosphorus concentration of 3.0 mg/l. In addition, sludge accumulation within the aerated cells was so excessive as to make phosphorus removal within an aerated lagoon facility impractical. Sludge accumulations of 1 - 1.5 inches/month (2.54 - 3.81 cm/month) were obtained for a 6-month period. Although effluent soluble phosphorus concentrations were very low (0.2 mg/l), high suspended solids content (100 mg/l) in the aeration cell effluent made it impossible to achieve low total phosphorus concentrations in the cell discharge. It was not possible to determine whether the high suspended solids in the aeration cells were the result of poor flocculation characteristics or excessive aerator mixing conditions possibly resulting in resuspension of chemical floc. As most facultative aerated lagoon facilities in this Province are followed by conventional stabilization ponds, it appears that the means of providing phosphorus removal at such wastewater treatment facilities would only be by direct chemical addition to the aeration cell effluent prior to entering the stabilization pond.

Since the studies involving continuous chemical addition to raw sewage entering conventional waste stabilization ponds have only been under way for approximately six months, steady state conditions in these systems have not yet been attained; consequently sufficient analytical data are not yet available to assess the effectiveness of this method of phosphorus removal. However, an earlier study involving alum addition to the influent of the stabilization

pond system indicated that a high degree of phosphorus removal could be obtained[10].

Three continuous flow lagoon systems are being studied using continuous chemical feed for phosphorus removal. Alum, ferric chloride, and lime are the three precipitants being used.

In the alum study, eighteen months of data at a dosage of 175 mg/l alum have shown that the raw sewage phosphorus level can be reduced by 80%. (9.8 mg/l down to 1.6 mg/l). In order to meet the 1 mg/l effluent P requirement, the dosage has recently been increased to 200 mg/l. This has resulted in a reduction in the effluent phosphorus value to 0.8 mg/l. It is expected that an effluent phosphorus value of 1 mg/l or less will be maintained.

The use of ferric chloride in a stabilization pond has been underway for seven months. Prior to initiating continuous chemical feed, the lagoon contents were batch treated to reduce the phosphorus level to less than 1 mg/l. To date, the effluent phosphorus level has consistently been below 0.8 mg/l with an average value of 0.3 mg/l. Average BOD and SS values of 15 mg/l and 25 mg/l respectively were obtained.

The addition of 175 mg/l lime to the raw sewage fed to a stabilization pond for a period of six months has resulted in a gradual reduction in the effluent phosphorus level to 3.0 mg/l from a normal 5.0 mg/l. A further reduction in effluent phosphorus levels is expected.

CONCLUSIONS

1. A satisfactory predictive technique has been developed that allows a rational selection of prime coagulant to be used for phosphorus removal at a WPCP.

2. Phosphorus removal was readily implemented with minimal capital expenditure at all municipal WPCP's studied.

3. Satisfactory effluent quality was attained by the activated sludge process and its modifications when phosphorus removal was practised. Increased sludge production was experienced in all systems with the sludge quality and quantity dependent upon the chemical used for phosphorus removal.

4. Anaerobic digestion of chemical sludges associated with phosphorus removal was successful; no significant phosphorus release was observed during anaerobic digestion.

REFERENCES

1. "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River", Vol. I, Summary, 1969.
2. Canada/United States International Agreement on Great Lakes Water Quality, April, 1972.
3. Canada/Ontario Agreement on the Lower Great Lakes, August, 1971.
4. "Simplified Procedures for Water Examination", AWWA Manual, M12, p 42, 1964.
5. "Guidelines for Conducting Treatability Studies for Phosphorus Removal", Ontario Ministry of the Environment, Sanitary Engineering Branch, April, 1972.
6. "Lime Treatment for Phosphorus Removal at the Newmarket/East Gwillimbury WPCP", Ontario Ministry of the Environment, Research Branch, May, 1972.
7. "Phosphorus Removal Studies at Little River Sewage Treatment Plant", Public Works Department, City of Windsor, 1972.
8. "Nutrient Removal at Windsor Sewage Treatment Plants", Public Works Department, City of Windsor, July, 1972.
9. "Centrifuge Dewatering of Lime Treated Sewage Sludge", Ontario Ministry of the Environment, Research Branch, May, 1972.
10. "The Effects of Influent Alum Injection on the Effluent from Continuous Discharge Lagoons", Ontario Ministry of the Environment, Research Branch, February, 1973.

PHOSPHORUS REMOVAL ON SECONDARY EFFLUENTS

by

Earl E. Shannon

Wastewater Technology Centre,
Environmental Protection Service.

PHOSPHORUS REMOVAL ON SECONDARY EFFLUENTS

1.0 INTRODUCTION

Generally, total phosphorus removal down to an effluent guideline of 1 mg/l can be achieved by primary or simultaneous (addition of chemicals to the aeration tank) precipitation. Post- (chemical addition to the secondary effluent) phosphorus precipitation only becomes necessary when more stringent effluent phosphorus levels are advised (e.g., wastewater treatment plant discharging to a small eutrophication-prone receiving stream or lake). Although it is usually assumed that post-precipitation processes have higher capital costs than primary or simultaneous systems and are more complex to operate, some countries -- for example, Sweden, with over one hundred post-precipitation plants in operation -- use the process routinely. Effluent total phosphorus levels in the order of .1 to .5 mg/l and BOD's less than 10 can be expected from a post-precipitation process.

Post precipitation requires the addition of separate equipment onto the existing secondary plant and most of this equipment and design criteria are drawn from the water treatment field. Some alternatives for post-precipitation are depicted in Figure 1, with the individual components being flash mixing, flocculation and clarification or the three combined in a reactor clarifier, pH adjustment (optional, depending on chemical or desirability of lime recovery) and filtration. Although the chemical precipitation steps may give good phosphorus removal alone, filtration is usually added to remove any carry-over floc to give total phosphorus residuals as low as .1 mg/l. Design aspects of the various

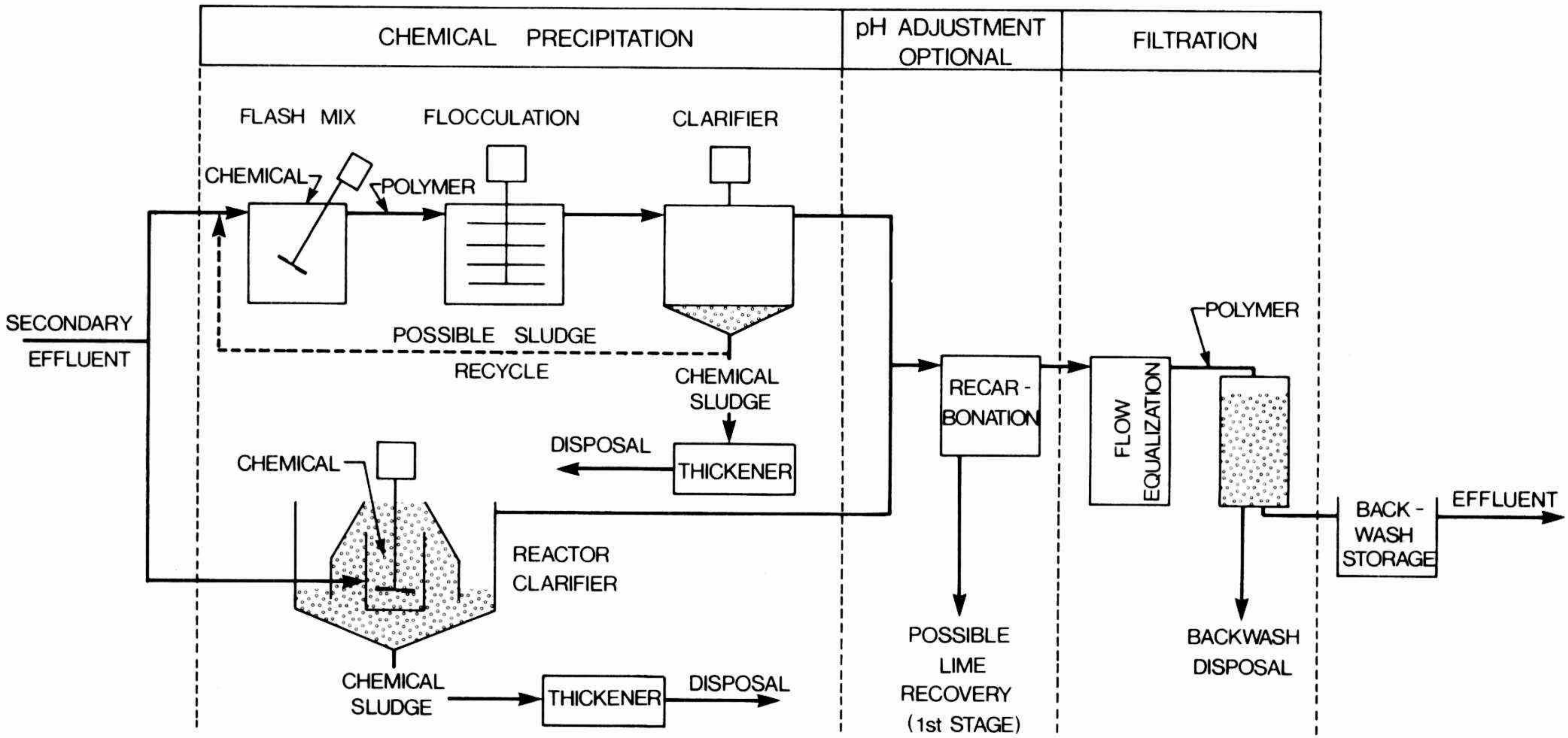


FIGURE 1: ALTERNATIVES FOR PHOSPHORUS REMOVAL FROM A SECONDARY EFFLUENT

stages in post precipitation will be discussed individually in the subsequent sections.

2.0 CHEMICAL PRECIPITATION

2.1 Selection of Chemical Precipitant

Traditionally, lime or alum are used as the chemical precipitants in post-precipitation schemes. Iron salts (e.g., $FeCl_3$) are seldom used because of the potential colouring effect that the iron doses may have on the final effluent. The choice between lime and alum will be based on (i) relative jar test effectiveness of the two chemicals on the wastewater to be treated, (ii) on the size of the plant, as it may affect chemical recycle [i.e., it is feasible to recarbonate, calcine and recover lime for a plant size in excess of 10 MIGD, Culp et al (1972), whereas present technology does not make alum recycle economically attractive at any size]. Design of the process, to be compatible with existing sludge-handling equipment, may dictate the chemical selected -- for example, tertiary lime sludges are denser and easier to dewater than their gelatinous alum counterparts.

Wastewater alkalinity, hardness, pH and other commiticant factors will influence the efficiency of the chemicals and, as a rule, the alum dose to phosphorus concentrations are more stoichiometric than in primary or simultaneous precipitation systems. There is still, nevertheless, some inherent (non-stoichiometric) chemical demand. Typically, alum doses of 200-300 mg/l are required to achieve total phos-

phorus residuals (after filtration) down to .1 mg/l. Lime doses are pH dependent and doses up to 500-600 mg/l are required to achieve the pH of 11.0 to 11.5 required for low phosphorus residuals. Although comparable phosphorus removal may be achieved at lower lime doses (300-400 mg/l), it is customary to use the high pH lime treatment (11.0) when lime recovery is to be practiced.

Culp (1972) has suggested that a good estimate of final effluent quality (chemical treatment plus filtration) may be obtained by analyzing the jar test supernatant after filtration through a Whatman #2 filter paper.

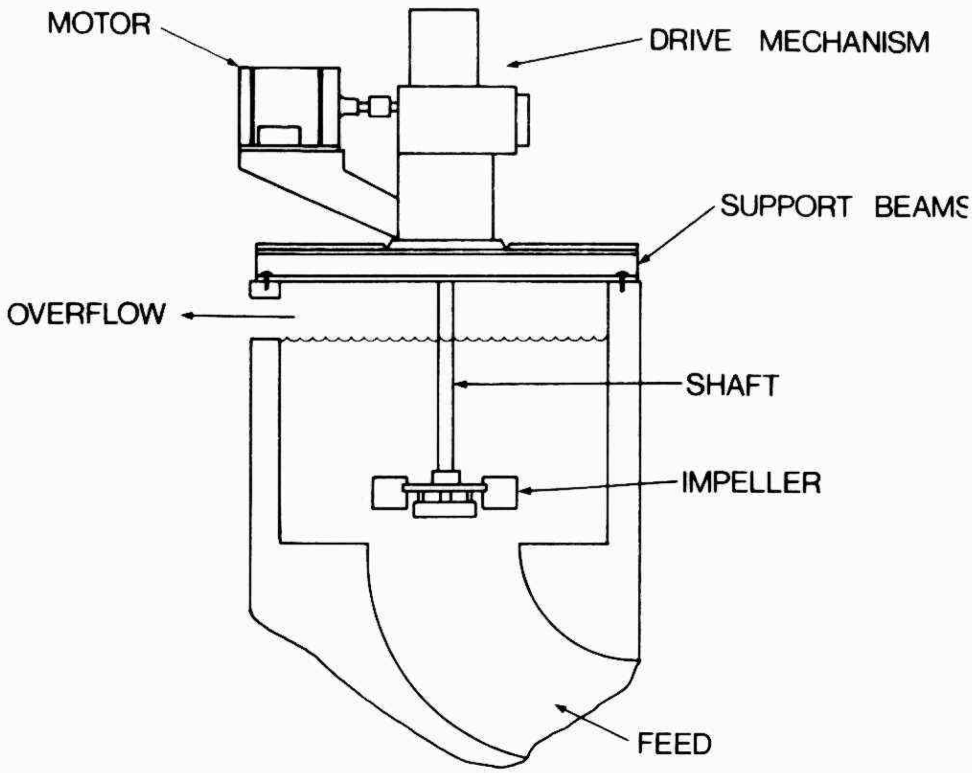
The chemical feed system, pump sizing and storage requirements will be governed by daily chemical consumption and these aspects have been discussed in previous sections of this seminar.

2.2 Flash Mixing Requirements

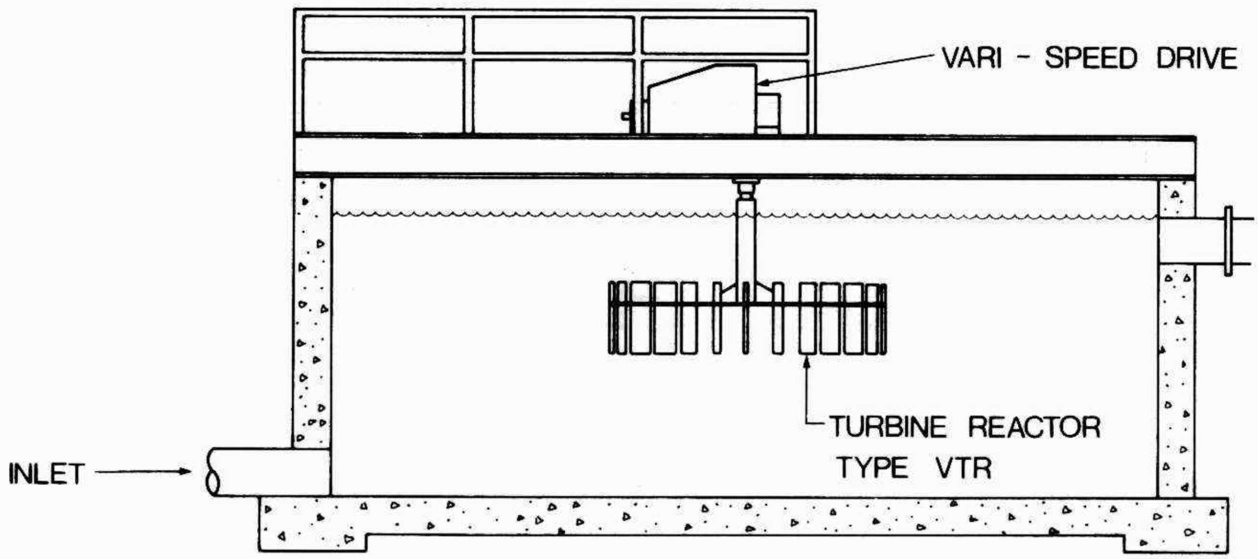
Water treatment technology is generally applied when designing flash mix and flocculation units. Criteria for flash mixers may be summarized as follows:

(i) detention time - 2 minutes at average plant flow with slightly higher retention times for lime (3 to 4 minutes) and possibly lower times (down to 1 minute) for alum. To provide flexibility and overcome repair problems, it is suggested that provision be made for two parallel units each designed to operate at a nominal capacity of one-half design flow;

(ii) mixer characteristics - should be properly baffled to prevent



(a) FLASH MIX UNIT (DORR - OLIVER)



(b) FLASH MIX UNIT (EIMCO)

FIGURE 2: TWO TYPICAL FLASH MIXER DESIGN

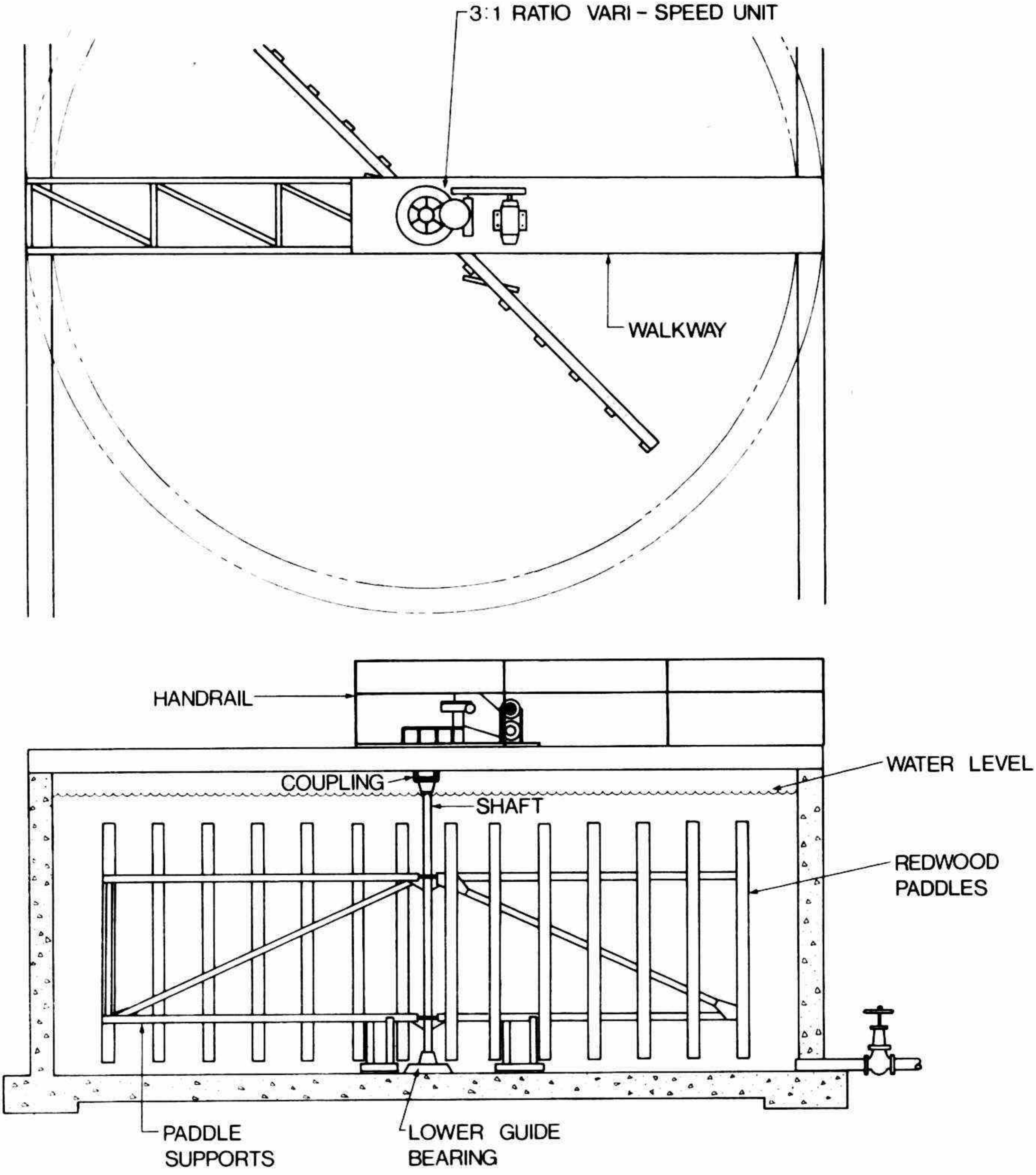


FIGURE 3: VERTICAL PADDLE FLOCCUATOR (EIMCO)

short circuiting -- mixer type and horsepower requirements are manufacturer-dependent, with typical shaft speeds being 300 to 400 RPM and horsepower requirements of .25 - 1.0 HP/MIG (two typical conceptual designs are shown in Figure 2);

2.3 Flocculator Design

After flash mixing, flocculation is employed to provide increased collisions between individual particles to incorporate them into a larger more rapid settling floc. At the same time, the kinetic energy provided in the flocculation step must not be high enough to cause floc break-up. The velocity gradients in the flocculation chamber are generally achieved by a system of slowly rotating wooden (redwood) paddles. Some traditional water treatment style designs employ horizontal paddles, whereas some more recent designs are of the vertical paddle type. Some design criteria for flocculators are summarized below:

(i) detention time - 15 minutes is generally the maximum required with a minimum in some cases as low as 5 minutes at average plant flow. Again, it may be prudent to design parallel units with a nominal capacity of one design flow each;

(ii) mixing characteristics - properly baffled tank to prevent short circuiting; basin depth 8 to 12 feet; paddle peripheral speeds of .6 FPM or provision for variable paddle speeds; paddle spacing for larger basins in the order of 24". (See the typical design in Figure 3.)

(iii) polymer addition - provision should be made for adding polymer

(anionic or cationic) in a dose range of .1 to .5 mg/l at the influent or effluent or both ends of the flocculator. Design aspects of polymer feed systems have been covered in a previous discussion. A typical flocculator design is shown in Figure 3.

2.4 Clarifier Design

Good solid-liquid separation is essential to the overall success of any chemical precipitation scheme. Consequently, design of the clarifier is most critical and Culp (1972) and others suggest that clarifiers be designed on the basis of maximum plant flow. Carry-over of solids from the clarifier can cause fouling of the downstream filter (if one is employed) or decreased phosphorus removals if clarifier effluent is discharged directly. Design criteria for clarifiers are listed below:

(i) overflow rates for conventional clarifiers

- for alum precipitated secondary effluent an overflow rate of 700 Igpd/ft^2 is recommended;
- lime precipitated secondary effluent overflow rates may range as high as 900 Igpd/ft^2 with the maximum hourly rate not to exceed 1400 Igpd/ft^2.

(ii) overflow rates for tube settlers

- generally 1.5 to 4 x higher than for conventional clarifiers and no rigid design data are available; however, rates in the order of 1500 Igpd/ft^2 to as high as 4000 Igpd/ft^2 have been suggested. (NOTE: Square footage refers to tube entrance area.)

(iii) sludge collection and pumping

- collection equipment should be of bottom scraper type;
- the sludge from a lime precipitation unit may vary from 1 to 5% solids with the total volume requiring handling being possibly as high as 7-8% of total flow;
- sludges from alum precipitation may vary from .5 to 1.0% solids;
- some investigators report that estimates of sludge quantity can be obtained from jar tests; however, this is risky and it is suggested that pumping capacity be of variable capacity designed to handle a maximum flow up to 9% of wastewater flow.

(iv) sludge recycle

- it may be desirable, with lime systems in particular, to recycle a portion of the sludge back to the rapid mix unit. A maximum recycle flow of sludge would be in the order of 10% of total sludge flow.

2.5 REACTOR-CLARIFIER DESIGN

As shown in Figure 1, the chemical precipitation step may be accomplished in a single unit incorporating flash mix, flocculation and clarifier steps (i.e., a reactor-clarifier). Many types of reactor-clarifiers are available from various manufacturers and it is beyond the scope of this discussion to deal individually with the various types.

The obvious advantage to a reactor-clarifier design is the conservation of space and total capital cost; however, the unit has an

obvious disadvantage. For example, Culp and Culp (1971) report that there is difficulty in maintaining a sludge blanket in the solids contact type because of fluctuations in the composition of the influent wastewater. A conventional chemical precipitation system usually offers more flexibility (i.e., manipulation of chemical and polymer dose and points of application) than a reactor-clarifier.

Very few design criteria exist for reactor-clarifiers and the design engineer must usually rely upon individual manufacturers for details of an integrated system and, in many cases, this system was initially designed for water treatment. A cutaway of the Graver Reactivator used in the Shagawa Lake Restoration Project [Wilcox (1972)] is shown in Figure 4.

3.0 RECARBONATION

When alum is used as the chemical precipitant, there is no need for pH adjustment on the clarifier effluent. However, when lime is used in a tertiary application, it is generally necessary to adjust the pH prior to filtering or discharge to the receiving water. If pH adjustment is the sole criterion, single-stage recarbonation (i.e., lowering of pH from the ambient levels down to approximately 7.0) is generally employed. If recovery of calcium carbonate which can be later recalcined to CaO is desirable, then two-stage carbonation (i.e., lowering of pH from 11.0 to 11.5 to 9.3 in the first stage and drawing off the $CaCO_3$ and further pH reduction in the second stage to approximately 7.0 to dissolve any residual $CaCO_3$ floc) is employed. In single-stage recarbonation, there is no

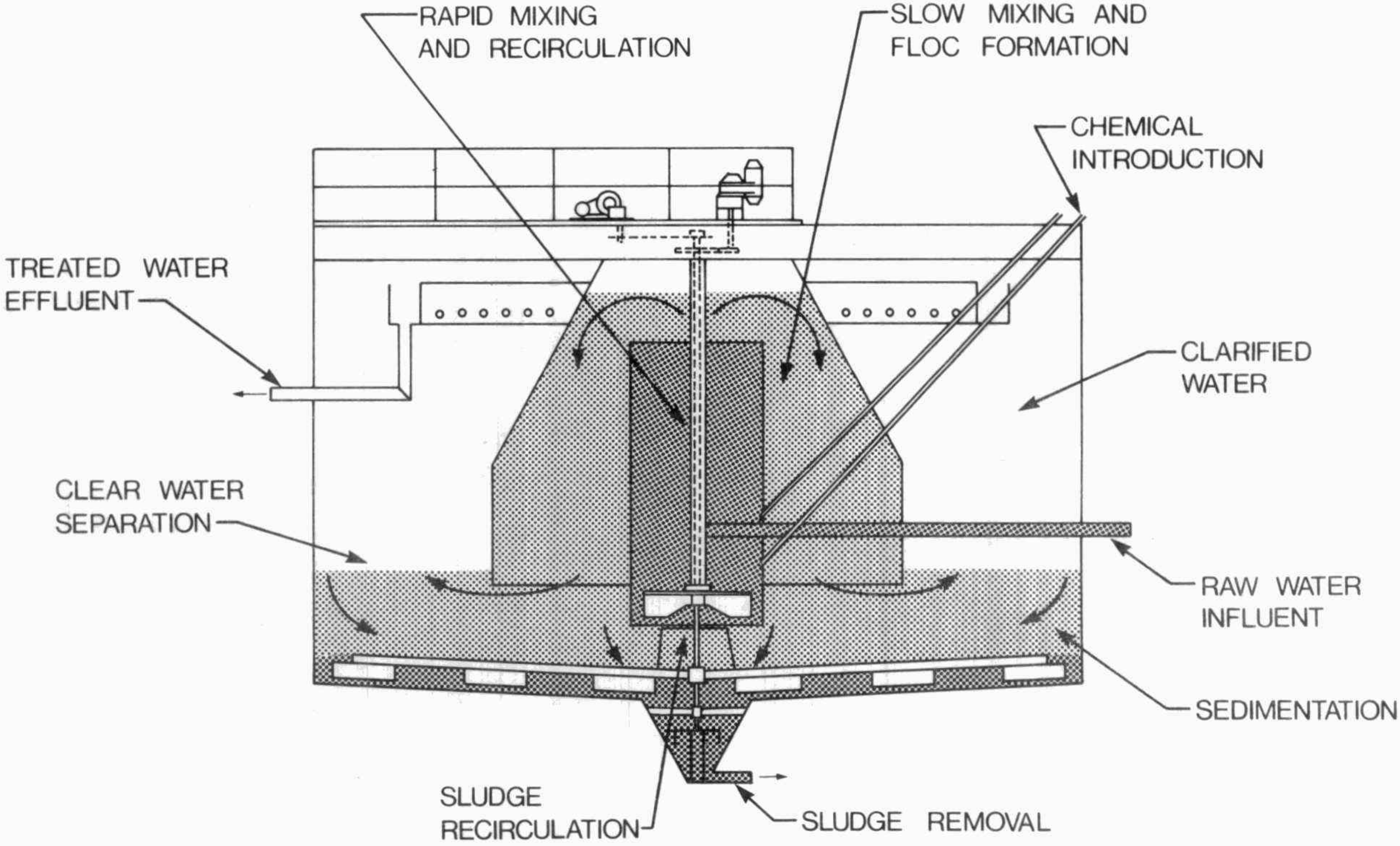


FIGURE 4: A REACTOR CLARIFIER (GRAVER WATER COND. CO.)

requirement for an intermediate settling basin. Some design considerations for recarbonation follow. For an extensive treatment of the topic see Culp and Culp (1971).

(i) Sources of Carbon Dioxide

- liquid CO_2, bottled CO_2 flue gas, recalciner gas, or fuel burner;
- selection of a particular source will be largely determined by the plant size.

(ii) Carbon Dioxide Requirements

- quantities may be estimated from the two following chemical equations:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2.$$

To convert $Ca(OH)_2$ to $CaCO_3$ (recovery of lime) requires 4.4 x (hydroxide alkalinity of the effluent mg/l as $CaCO_3$) lb/million Imperial gallons and to convert $Ca(OH)_2$ to $Ca(HCO_3)_2$ (single-stage) requires 8.0 x (hydroxide alkalinity) lb/million Imperial gallons. To account for inefficiencies in gas transfer, a safety factor of approximately 20% should be added to the calculated quantities.

(iii) Reaction Basin

- Culp and Culp (1971) recommend that the depth of water in the CO_2 reactor be at least 8 ft. deep to ensure good CO_2 absorption; (For a typical design see Figure 5)
- the detention time in the reactor and clarifier for $CaCO_3$

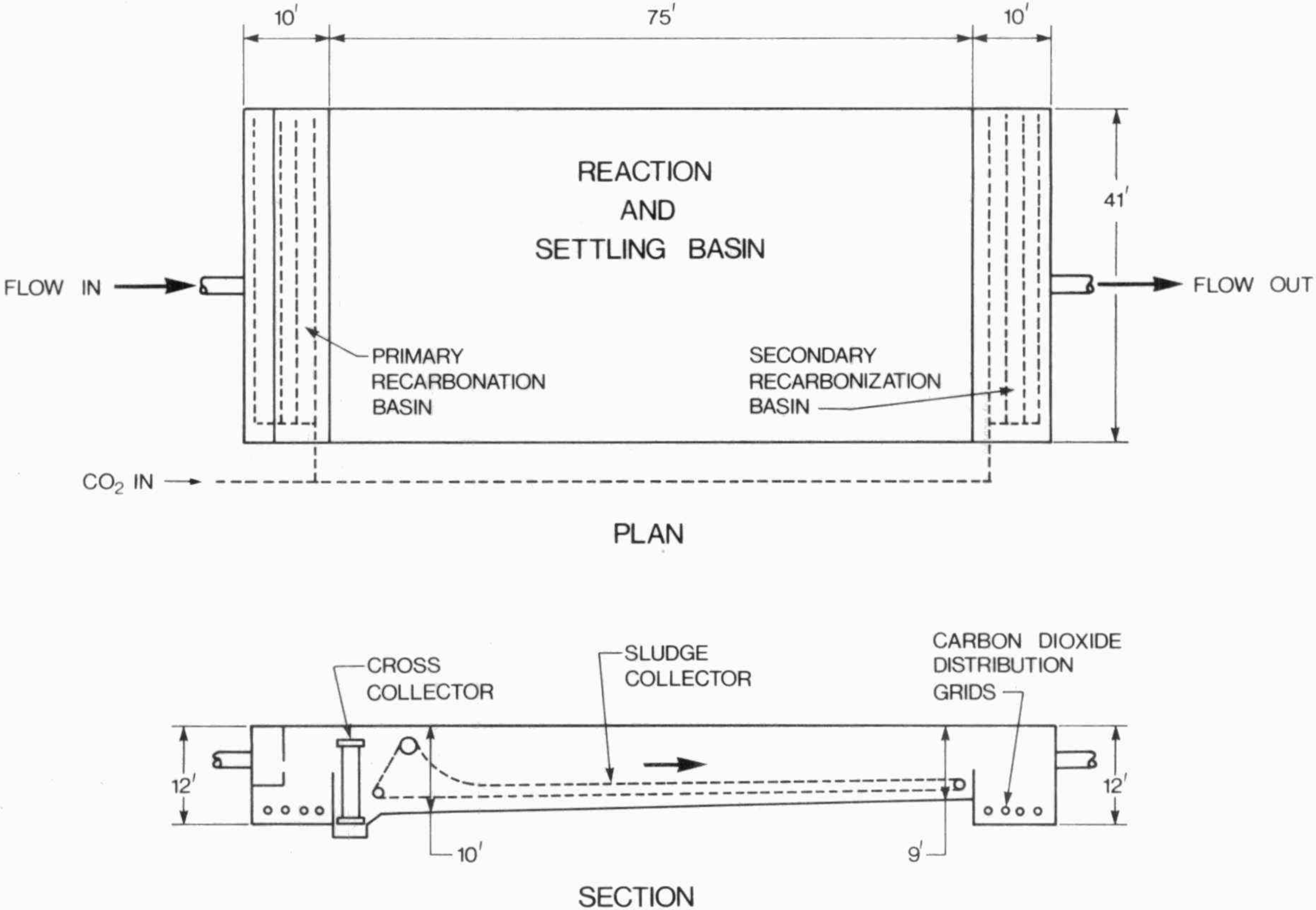


FIGURE 5: TWO - STAGE RECARBONATION BASIN WITH INTERMEDIATE SETTLING FOR 7.5 mgd PLANT. (CULP & CULP 1971)

recovery should be at least 30 minutes with an overflow rate less than 2000 I gal/ft^2/day;

- retention times recommended for CO_2 reaction are in the order of 15 minutes;
- CO_2 feed may be controlled by a pH senser with feed-back to a gas regulator.

(iv) Diffusion Systems

- CO_2 diffusion systems usually consist of a grid (1.5' square) of perforated pipe on the floor of the reaction basin;
- 3/16" perforations rated at 1.1 to 1.6 cfm and spaced at 3" intervals appear to be adequate for good CO_2 distribution and absorption;
- consideration must be given to corrosion resistance when hot and/or moist CO_2 sources are used.

4.0 FILTRATION

As indicated in Figure 1, the effluent from the clarification stage may be filtered before ultimate discharge. The filtration will remove any carry-over particulate matter (floc, or other suspended solids) thus making possible lower effluent residual phosphorus and turbidity levels. It should be pointed out that when lime is used as the precipitant, followed by recarbonation, most of the carry-over calcium-phosphate floc will be resolubilized in the recarbonation step and little, if any, additional phosphorus removal will be achieved by filtration. In this

case, the filtration will serve only to remove carry-over $CaCO_3$ and turbidity.

Several types of filtration have been applied to the treatment of chemically treated effluents and, overall, the dual or mixed-media type appears to be most applicable. Traditional slow sand filters are costly to install and operate and are relatively inefficient. With rapid sand filters, most of the headloss will occur in the upper inch of the bed leading to short filter runs and frequent backwashing. Microscreens have a tendency to break up alum flocs, thereby permitting the material to pass the screen.

4.1 MIXED-MEDIA FILTRATION

The design of the mixed-media filter is similar to a rapid sand filter except that the media are graded from coarse at the top to fine at the bottom, using different density and sized particles. A typical design is shown in Figure 6. Because of the gradation in pore size a greater depth of the filter bed is effective in suspended solids removal. Mixed-media filters can be operated in gravity or pressure modes with the pressure units generally being used at smaller installations. Some design considerations for mixed-media filters follow:

(i) flow rate

- maximum of 2.5 I gpm/ft^2 for gravity flow and 4.2 I gpm/ft^2 for pressure filters; however, rates as high as 8.0 I gpm/ft^2 may be employed at periods of peak flow for pressure filters;

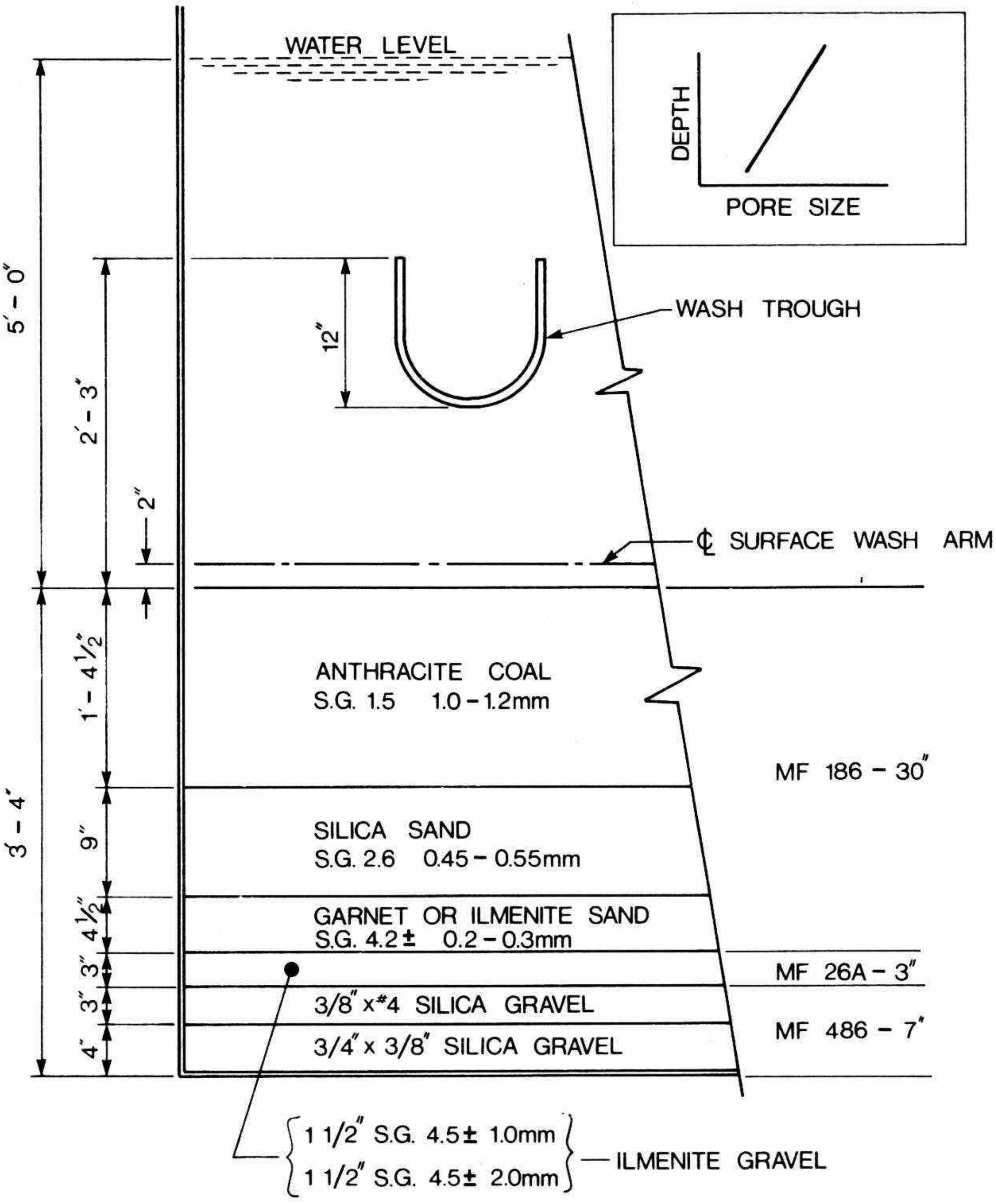


FIGURE 6: TYPICAL MIXED MEDIA FILTER
(NEPTUNE MICROFLOC INC.)

(ii) depth

- generally a 30-inch depth is sufficient for most applications;

(iii) backwash

- provision should be made for backwash storage (usually treated effluent) sufficient to backwash the filter for 5 minutes at a flow rate of 3 to 4 X treatment flow (i.e., 12 - 16 I gpm/ft^2);

(iv) surface wash

- to break up any surface build-up on the filter a surface backwash system which starts before actual backwashing (1 - 2 min. duration) and discharges at the rate of 1 - 2 I gpm/ft^2 is recommended;

(v) flow equalization

- storage facilities should be provided to equalize any flows that are greater than 1.5 X filter design flow. See Culp and Culp (1971) for further details on equalization;

(vi) filter aids

- provision should be made for adding a polymer as a filter aid directly before the filter at a dose range of .01 to .1 mg/1.

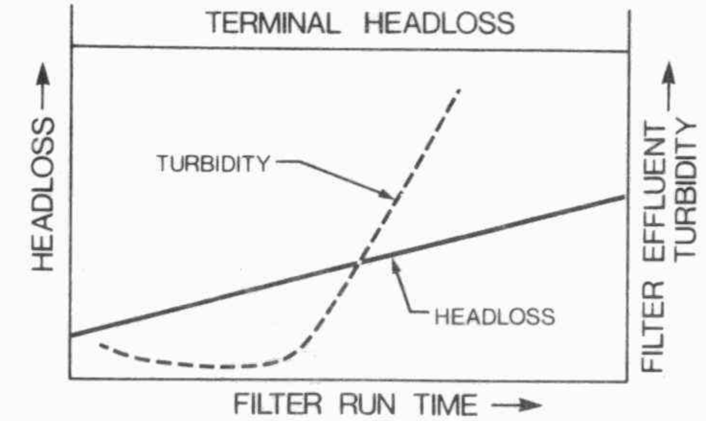
4.2 OPERATIONAL CONSIDERATIONS

Generally, it is desirable to monitor the effluent quality from the filter via continuous turbidity measurements. Headloss settings and polymer dosages are then manipulated so that filter break-through and the backwash initiating headloss occur almost simultaneously. The

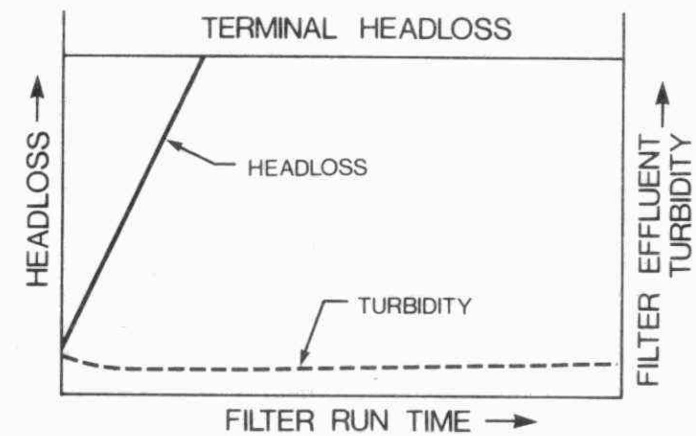
relationships between polymer dose and headloss setting are depicted in Figure 7.

Backwash and surface wash sequences are generally completely automated. The quantity of backwash and surface wash water may vary anywhere from 1 to 10% of the total flow treated, depending on the quality of the filter influent.

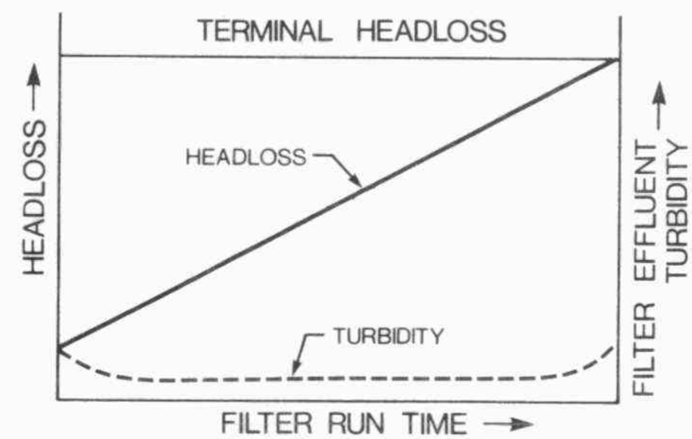
- - - - - - - - - - - - - - -



(a) POLYMER DOSE INADEQUATE



(b) POLYMER DOSE EXCESSIVE



(c) OPTIMUM POLYMER DOSE

FIGURE 7: EFFECTS OF POLYMERS AS FILTER AIDS (CULP & CULP 1971)

SELECTED REFERENCES ON POST-PRECIPITATION

1. ATKINSON, J.W., "Practical Experience in the Use of Polyelectrolytes", Water Treatment and Examination, Vol. 20, Part 3 (1971)

2. BELL, F., Practical Experience in the Use of Polyelectrolytes", Water Treatment and Examination, Vol. 20, Part 3 (1971)

3. COMMITTEE REPORT, "State of the Art of Coagulation -- Mechanisms and Stoichiometry", Jour. Amer. Water Works Ass'n., 63, 99 (1971)

4. CONLEY, W.R., and HSIUNG, K. Y., "Design and Application of Multi-media Filters", Jour. Amer. Water Works Ass'n., 61, No. 2, (Feb. 1969)

5. CULP, G., "Secondary Plant Effluent Polishing: Part 1", Water and Sewage Works (April, 1968)

6. CULP, G. L., "Tube Clarification Process, Operating Experiences", Jour. San. Eng. Div., Proc. Amer. Soc. Civil Eng. 95, SAS 829 (1968)

7. CULP, R.L., EVANS, D.R. and WILSON, J.C., "Advanced Wastewater Treatment as Practiced at South Tahoe", EPA Water Pollution Control Research Series #17010ELQ 08/71 (1971)

8. EVERS, R.H., (Neptune-Microfloc Inc., Corvallis, Oregon), "Tool Up with Mixed-Media Filters", Water Wastes Eng., Ind., (May, 1971) C14-C16 (Eng.), Pub. in Water Wastes Eng. 8 (5)

9. HANSON, S.P., "Practical Application of Idealized Sedimentation Theory", Jour. Water Poll. Control Fed., 41, (1969)

10. HANSON, S.P., and CULP, G.L., "Applying Shallow Depth Sedimentation Theory", Jour. Amer. Water Works Ass'n., 59, No. 9 (Sept., 1967)

11. HILSON, M.A., "Practical Experience in the Use of Polyelectrolytes", Water Treatment and Examination, Vol. 20, Part 3 (1971)

12. HUNTER, R.W., "Practical Experience in the Use of Polyelectrolytes", Water Treatment and Examination, Vol. 20, Part 3 (1971)

13. IVES, K.J., "Rapid Filtration", Water Research, 4, No. 3 (March, 1970)

14. JORDEN, R.M., "Coagulation - Flocculation", Water Sewage Works, 118 (1), 23-5 (Eng.), (1971)

15. KREISSL, J.F., et al, "Use of Pilot Filters to Predict Optimum Chemical Feeds", Jour. Amer. Water Works Ass'n., (March, 1968)

16. McGARRY, M.G., "Algal Flocculation With Aluminum Sulphate and Polyelectrolytes", Jour. of WPCF (May, 1970)

17. PURCHAS, D.B., "Flocculation and Coagulation", Process Bio-Chem. (Brit.) 3, 17 (1968), Water Poll. Abstracts (Brit.), 42, 974 (1969)

18. RIES, H.E., and MEYERS, B.C., "Flocculation Mechanism: Charge Neutralization and Bridging", Science 160, 1449 (1968)

19. RUSSO, F., "Polyelectrolytes, Coagulant Aids and Flocculants", Water Sewage Works, 117 (ref. No.), (1970)

20. SHEA, T.G., et al, "Experimental Evaluation of Operating Variables in Contact Flocculation", J. Amer. Water Works Ass'n., 63 (1971)

21. SHIREMAN, H.C., "Filtration Boosts Tertiary Treatment", Water and Wastes Engineering (April, 1972)

22. TCHOBANOGLORS, G., "Filtration Techniques in Tertiary Treatment", Jour. WPCF, 42, No. 4 (April, 1970)

23. TEBBUTT, T.H.Y., "An Investigation into Tertiary Treatment by Rapid Filtration", Water Resources (G.B.) 5, 81 (1971)

24. TENNEY, et al, "Algal Flocculation with Synthetic Organic Polyelectrolytes", Applied Microbiology, 18, p. 965-971, (Dec. 1969)

25. TEOT, A.S., and DANIELS, S.H., "Flocculation of Negatively Charged Colloids by Inorganic Cations and Anionic Polyelectrolytes", Environmental Science and Technology, p. 825, (Sept., 1969)

26. WILCOX, R.L., "Removing in Excess of 99% Phosphorus at Ely, Minnesota", Paper presented at 73rd Meeting of Amer. Institute of Chemical Engineers, Minneapolis, Minnesota, August (1972)

27. YAO, K.M., et al, "Water and Waste Water Filtration: Concepts and Application", Environmental Science and Technology, 5, 1105 (1971)

28. CULP, R.L., and CULP, G.L., "Advanced Wastewater Treatment", Van Nostrand Reinhold Co., (1971)

29. EVANS, et al, "Advanced Wastewater Treatment as Practiced at South Tahoe", Environmental Protection Agency - Water Quality Office, (Aug., 1971)

30. BROSMAN, D.R., and MALINA, J.F., "Intermixing of Dual Media Filters and Effects on Performance -- Technical Report", Center for Research in Water Resources, Univ. of Texas (1972)

SOME PLANT DESIGN CONSIDERATIONS IN PHOSPHORUS REMOVAL FACILITIES

Prepared for:

Phosphorus Removal Design Seminar

Canada-Ontario Agreement on
Great Lakes Water Quality

Skyline Hotel, Toronto, Ontario
May 28 - 29, 1973.

G. A. Aldworth,
Group Manager, Technical Services,
JAMES F. MacLAREN LIMITED

INDEX

INTRODUCTION

This paper is concerned with those areas related to detail design for phosphorus removal, and presupposes that the fundamental process aspects are well in hand. Topics will include:

a) Effects of encrustation and corrosion
b) Representative chemical feed systems
c) Effect of chemicals on plant elements such as air diffusers, pumps, tanks, piping, etc.

It is apparent that phosphorus removal from municipal sewage requires relatively large dosages of chemicals - say 100 to 300 mg/l of lime as $Ca(OH)_2$, and 10 to 20 mg/l of alum as Al^{+3} or ferric chloride as Fe^{+3} - so this paper will emphasize schemes involving the storage and feeding of large amounts of chemicals received in bulk form.

Should this paper overlap with others in this seminar, please accept my apologies - but the opportunity to attack a "miscellaneous design" paper gives the writer a rare excuse to stray beyond the normal guidelines!

LIME TREATMENT

SUMMARY OF PROCESS

Lime treatment involves adding lime slurry to raw sewage upstream of primary settling, and may be supplemented by lime sludge recirculation to maximize dosing efficiency or by lime recovery using thermal methods to minimize chemical costs.

When lime is applied to raw sewage, it functions to precipitate the temporary hardness, raise the pH to about 9, tie up the dissolved phosphorus chemically, and drop it out as a lime sludge. It is noted that higher dosages are required for those sewage streams having higher temporary hardness.

After primary settling, the main stream of relatively high pH (say 9) enters an aeration tank where the carbon dioxide produced tends to neutralize the alkaline sewage and reduce its pH to about 7½, thereby obviating biological upset. Any lime carry-over from the primaries is thought to be converted to the bicarbonate state in an aeration tank, so no encrustation is experienced.

BASICS

a) Total Hardness (Usually Ca^{++} & Mg^{++} ions)

i) Temporary (or carbonate)
- $Ca(HCO_3)_2$
- $Mg(HCO_3)_2$

ii) Permanent (or non-carbonate)
- $Ca\ SO_4$, $Mg\ SO_4$
- $Ca\ Cl_2$ $Mg\ Cl_2$

In general, the predominant constituent is temporary hardness which, for example, amounts to 100 mg/l in Lake Ontario relative to a total hardness of 135 mg/l.

b) Effect of Lime on Temporary Hardness in Raw Sewage

$Ca(OH)_2 + Ca(HCO_3)_2 = 2CaCO_3\downarrow + 2H_2O.$

The precipitated carbonate shows up as a slime which is rather soft when submerged, but relatively hard when exposed to air.

The amount of slime is a function of lime dosage and resultant pH, there being less build-up at higher pH levels (9.5 to 10) and virtually no build-up at 10.5 to 11. Since most primaries are at or below a pH of 9.5, some sliming can be expected. It is noted that lime sludge recirculation tends to reduce slime build-up.

c) Effect of Carbon Dioxide on Lime-Treated Sewage

$CO_2 + Ca(OH)_2 = CaCO_3\downarrow + H_2O$

$CO_2 + H_2O + CaCO_3 = Ca(HCO_3)_2$

When sewage cascades in air, over primary effluent weirs for example, some of the excess lime may be converted to slime as shown above.

The desired effect in lime softening plants is to drop out excess lime as shown above (recarbonation), however, it is necessary to keep the pH over 9 or bicarbonate will result instead.

The opposite is thought to be the case for lime carry-over to a sewage aeration tank, as the pH is driven down well below 9 by the neutralizing action of carbon dioxide released from the waste water.

The resultant formation of bicarbonate instead of carbonate is very important in diffused air plants, as the carbonate would very quickly clog fine-bubble air diffusers. However, this has not been experienced in actual operation, and Richmond Hill S.T.P. - for example - has operated with lime for about 8 months without diffuser clogging.

However, one should be careful of adding lime directly to aeration tanks such as was done some years ago at the Mill Creek S.T.P. in Cincinnati, Ohio. Here the temporary hardness was still in the sewage, and the resultant slime dropout clogged the fine-bubble diffusers in a matter of minutes!

EXPERIENCE OF NEWMARKET S.T.P.

Background

Type of plant: Conventional activated sludge using mechanical aerators.

Rating: 2 MIGD

Raw Sewage:
- pH @ 8.3
- hardness @ 300 mg/l
- alkalinity @ 450 mg/l

Lime dosage: approx. 200 mg/l - as $Ca(OH)_2$

Settled Sewage: pH @ 9 (i.e. after lime treatment)

Encrustation

The problem of slime build-up has been surprisingly small at Newmarket.

a) Tanks

There is virtually no build-up on submerged surfaces in tanks, and what does form is relatively soft. However, slime does build up at points where sewage cascades in air such as primary influent channel discharge point (approx. 18" drop into feed well) and primary effluent weirs. The action here is thought to be a result of CO_2 in the air combining with excess lime as described before.

It is practice for plant operators to knock off the build-up in channels etc. once a week, but the task is not considered onerous.

b) Process Equipment

A build-up of lime chunks was initially experienced on the blades of the mechanical mixer in the Rapid Mix Tank. This was thought to be undissolved lime - $Ca(OH)_2$ - rather than precipitated carbonate - $CaCO_3$. This bothersome and unsightly problem was eventually overcome by means of lime recirculation (faster increase of pH), and better dispersal of lime slurry at application point using a coarse-bubble air diffuser. Presently, there is no problem here.

No untoward problem has been experienced with clarifier mechanisms in respect of encrustation or corrosion, so conventional apparatus should continue to be used. However, it is of interest to note that at Atlanta's Chattahochee lime-softening water treatment plant, steel circular mechanisms were replaced in a short period of time with stainless steel units due to recurring corrosion problems.

c) Main Conduits

With respect to main sewage conduits between Rapid Mix and Primary Tanks, it is important to use open channels rather than enclosed pipes whenever possible in order to be able to clean out build-ups of carbonate and undissolved lime. At Newmarket the influent pipe to the square-X primary clarifier is submerged, and access through an elbow for cleanout purposes is difficult. It was necessary to construct an open channel above water level to supplement the constricted pipe under high flow conditions. In new plant design, this will be a difficult problem to resolve as the open channel gets in the way of the moving surface skimmer.

Sludge Pumps

Sludge from lime treatment is surprisingly high in solids, i.e. up to 15% solids from the primaries and up to 28% from the digesters. It is of interest that a lime sludge is easier to pump than an ordinary sludge which becomes gelatinous and unpredictable at higher concentrations. The lime sludge can be handled by conventional positive-displacement plunger pumps for primary tank service, and by standard centrifugal non-clog pumps for digestion tanks, as operation in both cases is intermittent. Where continuous pumping is intended such as lime-sludge recirculation, a centrifugal pump of abrasion-resistant construction is required such as Ni-hard. For such service, there is a weighing of the better solids passing capability of a torque-flow pump against the better suction lift capability of a non-clog enclosed-impeller pump. At Newmarket S.T.P. the torque-flow unit has given excellent service, so this would appear to be the better choice.

LIME SYSTEMS

Chemical Details

Hydrated Lime: $Ca(OH)_2$ @ 35 lb/cu.ft. and 68% CaO

Quick Lime: CaO @ 55 lb/cu.ft. and 90% CaO

Alternative Systems

Reference is made to Fig. 1 "Representative Lime Systems" attached hereto showing alternatives for bulk lime. This is thought to be appropriate for most plants as bulk hydrated lime - $Ca(OH)_2$ - is often used for plant consumptions over 1/4 ton per day (avg.), and bulk quick lime - CaO - is often used over 1 tank truck per month or 1/2 ton per day (avg.). For those plants which consume less, a conventional feed system involving bagged storage, manual loading hopper and volumetric feeder located close to application point is often used.

a) Fig. 1A: Hydrated Lime - Wet Storage

In this system, hydrated lime is stored as a lime-slurry in a tall steel circular tank outside having a special abrasion-resistant pump directly below. The pump functions to recirculate tank contents continuously thereby avoiding deposition, and to supply a day tank intermittently when required. The tank truck unloading sump with rapid mixer can be located at ground level using an auto level control valve or at the top of the storage tank using weir overflow control. In either case, the main storage tank is filled with a known quantity of water which is recirculated through the unloading sump until the bulk truck is empty. The main storage tank can be outside, but requires heat and insulation.

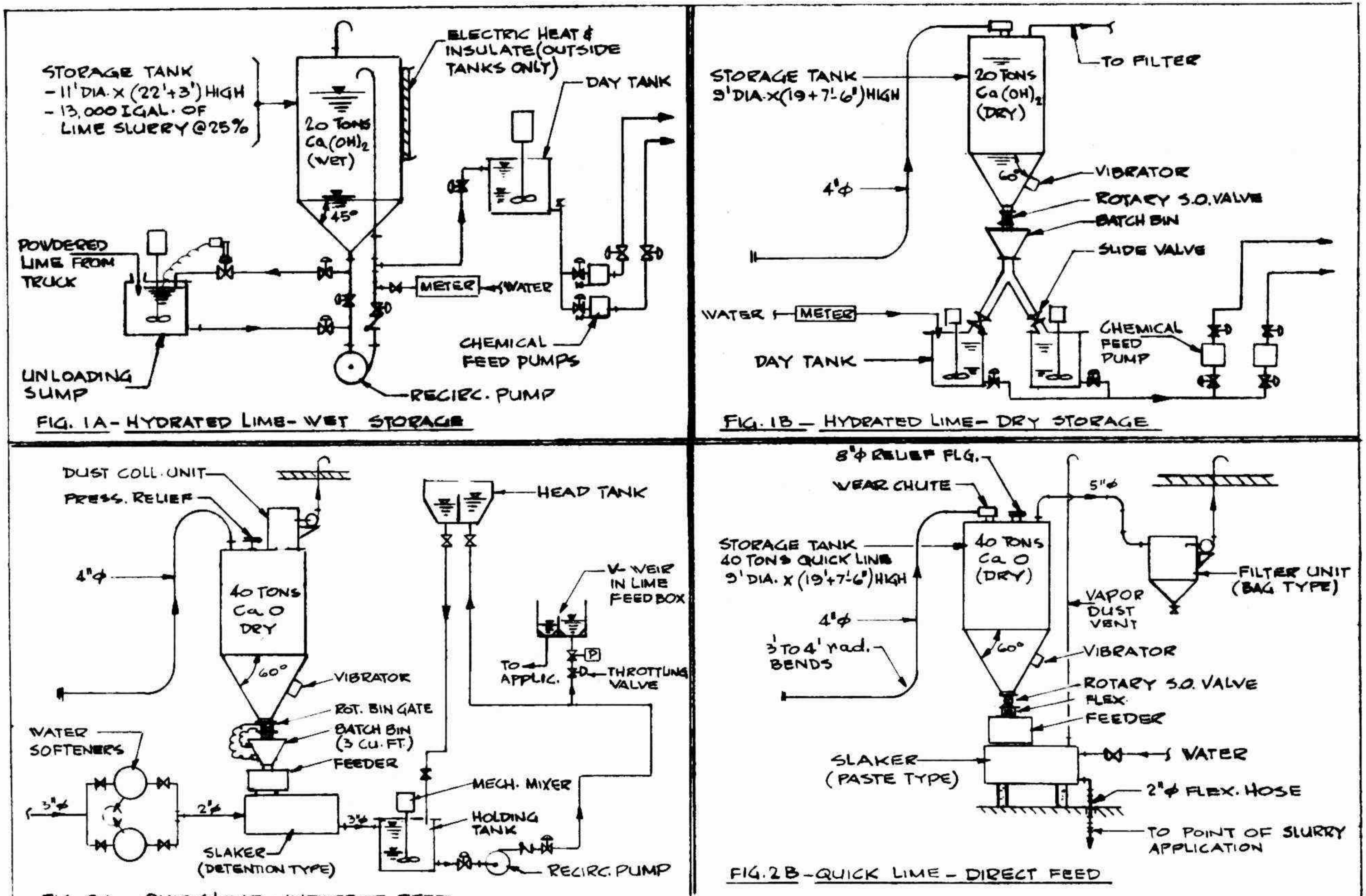


FIG. 1 REPRESENTATIVE LIME SYSTEMS

There is a variation of this system using a circular squat ground storage tank, however this requires a large mechanical mixer to avoid deposition.

Advantages of the system include carbonate deposition in the large storage tank rather than in the piping, and avoidance of handling problems with lime powder due to absorption of airborne water vapour and carbon dioxide when in dry storage.

Such a system has functioned well at London's Greenway S.T.P. where the primary lime slurry at about 25% solids is diluted in a day tank prior to final feeding with special diaphragm pumps having dual check valves.

b) Fig. 1B: Hydrated Lime - Dry Storage

In this case, the main storage tank can be slightly smaller and requires no heating or insulation, however the cone angle must be steeper and a mechanical vibrator used to ensure against hang-up arching. A slurry is made up on a batch basis in day tanks.

This system features simplicity, but has one disadvantage in that some chemical feeder pumps, having restricted discharge head capability of about 25', can be situated too low in the building.

c) Fig. 1C: Quick Lime - Indirect Feed

In some systems, the lime slurry make-up (feeder/slaker) is remote from the application point, thus requiring a lime slurry transfer system. A number of problems were experienced in such an installation which may be worthwhile reviewing here:

- If there is no vibrator on the storage tank cone, a sledge hammer is the only alternative in avoiding hang-up!

- There were problems with a belt feeder. Operators developed an effective worm feeder for quick lime service.

- Detention slaker did not function well as slaking temperature was always too cold.

- Grit removers were found to be a definite necessity.

- Lime slurry piping should be as simple as possible; no cross-overs, minimum valves, etc. It should be accessible using a step ladder (i.e. not more than 8' above floor).

- Rubber hose is preferred to Series 120 PE pipe which is too difficult to work with.

- Provide two pipelines, one for duty and other for standby.

- Avoid small (3/4") vertical lines with valves at bottom, as lime tends to pack on the top of the valve after shut-off and cannot be resuspended.

- Flush out all piping after shut down.

- The use of water softeners on supply water to the slaker (for avoiding carbonate build-up) was found to be not really required.

d) Fig. 1D: Quick Lime - Direct Feed

Where it is possible to locate the feeder/slaker near the application point, as shown here, this is the preferred system to use. Problems associated with transferring lime slurry are virtually eliminated, as a simple length of flexible rubber hose is all that is used.

This system has functioned well at the new Saint John, N.B. Spruce Lake Water Treatment Plant. In particular, the paste-slaker, which uses minimum supply water and therefore attains high operating temperature, has given good service.

It is of interest that hydrated lime can also be used when desired in this system, in which case the slaker becomes a nominal wetting agent only.

PIPING

For lime slurry transfer service in sizes 2½" and over, we have found a good piping system to be pipe of Schedule 40 black steel, Victaulic (mechanical-groove) connectors, and mechanical-groove fittings of malleable iron. Valves would be straightway diaphragm type with C.I. body, or possibly mechanical-groove butterfly type.

For 2" dia. and under, flexible rubber hose is best for long runs, as it may be readily dismantled, run over with a truck before clean-out and restored to service. Another system worth considering is Schedule 80 ABS pipe with special Victaulic connectors and long sweep elbows. The ABS provides a smooth wall together with good impact resistance so that it may be rapped smartly with a mallet for cleanout, and the Victaulic connectors provide for quick disassembly.

Velocity of lime slurry should be reasonably high to avoid deposition and in any case above 2½ fps. This is sometimes difficult to achieve, particularly in feed pump lines, however diluting the slurry can help. Also, high capacity flushing points are mandatory, and should always be used after shut-down.

ALUM OR FERRIC CHLORIDE TREATMENT

SUMMARY OF PROCESS

Multivalent metal ions from salts such as alum and ferric chloride, which tie up the phosphorus chemically, are often added before the final clarifier in the secondary portion of a plant.

BASICS

Liquid Alum: $Al_2(SO_4)_3 \cdot 14\ H_2O$ @ 1.3 SG and 48% commercial strength

Liquid Ferric Chloride: $FeCl_3$ @ 1.4 SG and 40% commercial strength

There are, of course, other chemicals such as ferrous sulphate, but these will not be dealt with in this paper.

CORROSION

General

Both chemicals are highly corrosive and generally require the inert plastics for containment. Ferric chloride is so potent that it will atack even Type 316 stainless steel.

Ferric Staining

Wherever ferric is handled at a plant, there is a pervasive objectionable staining of concrete and other surfaces which is virtually impossible to remove. About all one can do is to provide shallow containment sumps in critical areas - tank truck unloading, storage tanks, metering pumps, etc. - to catch the drips and spills. Such sumps should be provided with a depression where ferric droppings can be extracted

periodically by inert plastic ejector and discharged to the main sewage stream.

It is of interest that experience at Newmarket S.T.P. indicates activated sludge to be a good clean-up agent for ferric spills - this being discovered quite accidentally by plant operators.

One aspect at Newmarket which surprised the writer was the rusty-red colour of the mixed liquor in the aeration tanks as a result of some prototype test work being carried out with ferrous salts. However, no untoward corrosion effect on submerged equipment is evident.

FEED SYSTEMS

Reference is made to Fig. 2 "Representative alum or ferric chloride systems", showing open and pressurized storage alternatives for these chemicals.

Tank size is related to both average plant consumption and bulk tank truck delivery - the latter being in lots of approx. 3100 I. gal. Unit storage tank volumes therefore range between 5000 and 13,000 I. gal., the latter restricted by trucking between fabricating shop and plant site.

a) In Fig. 1A "Open Storage", the storage tank is of vertical configuration in FRP construction, as this is most economical for the subject service. This system requires centrifugal transfer or positive-displacement feed pumps taking suction directly from the tank.

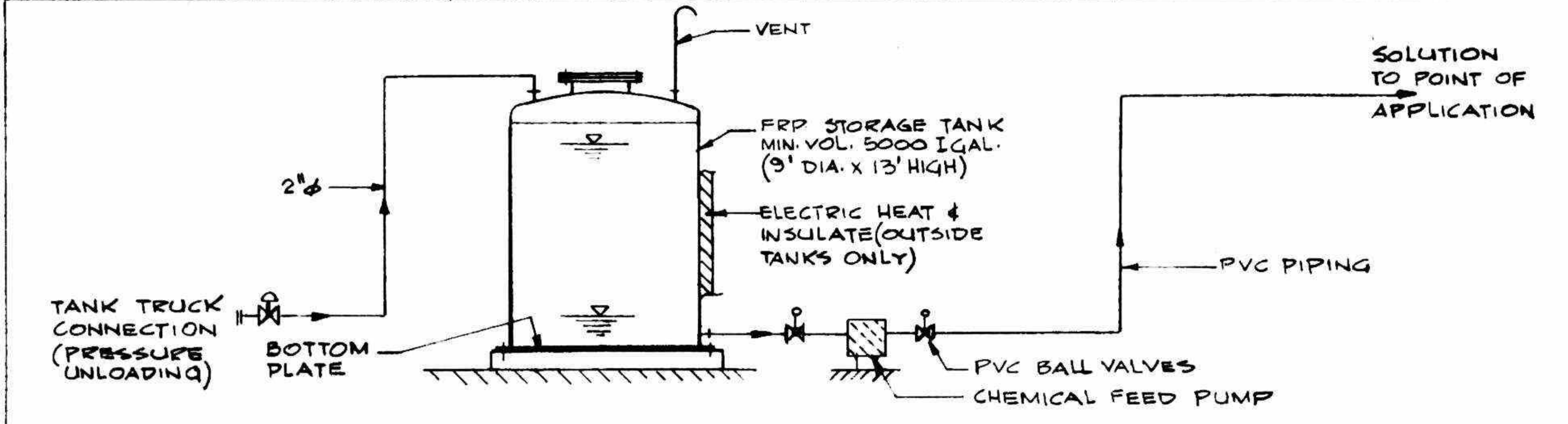


FIG. 1A. – OPEN STORAGE

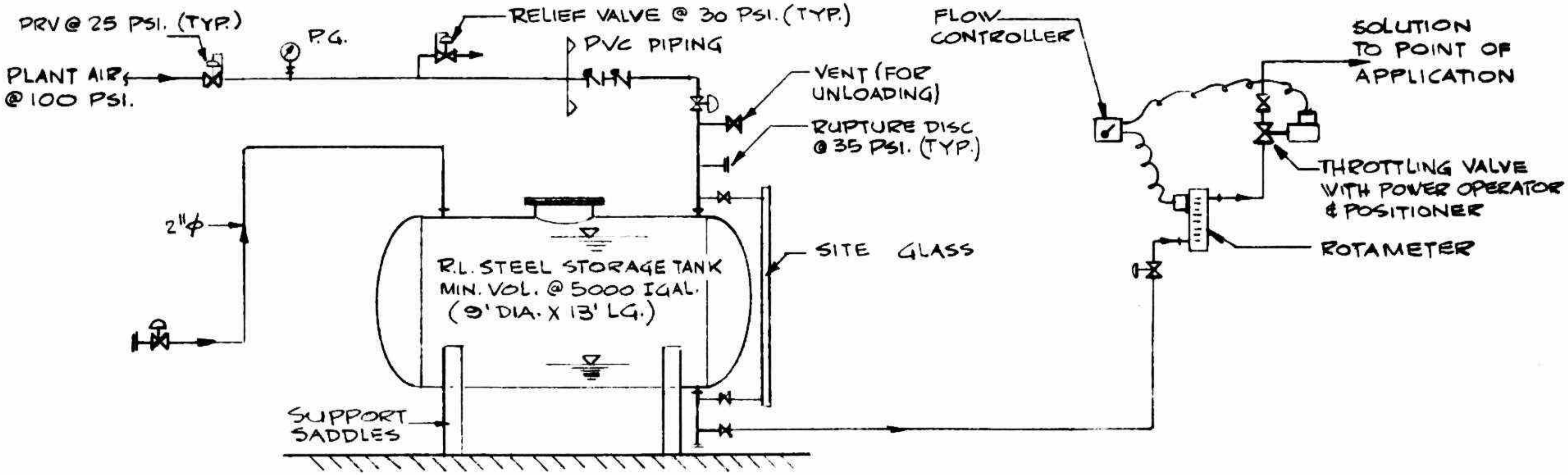


FIG. 1B. – PRESSURIZED STORAGE

FIG. 2 REPRESENTATIVE ALUM OR FERRIC CHLORIDE SYSTEMS

b) Where such pumps are not desired, the air pad system as shown in Fig. 1B "Pressurized Storage" is often used, and the chemical solution is metered through a flow-meter, controller, and throttling valve arrangement. The storage tank is shown to be of rubber-lined steel as this is generally most suitable for pressure service above 15 psi. The tank should be fabricated in accordamce with the ASME Unfired Pressure Vessels Code and, as such, both pressure-relief valve and rupture disc are needed. Although 33 per cent more expensive than an open FRP tank, the pressurized RL steel tank features greater robustness, lesser spill potential, and lesser staining around the storage area (i.e. no pumps).

The pressurized storage system has been used successfully on ferric chloride service in some large sewage treatment plants.

c) Exterior storage tanks for alum and ferric chloride should be heated and insulated during cold weather - although the need on ferric service is marginal. FRP tanks can be fitted with low density electric heaters (either surface mounted or resin embedded) and covered with rigid polyurethane foam. This can be done in the fabricator's shop, so the cost extra is not excessive. On the other hand rubber-lined steel tanks are generally fitted in the field with standard heating (electric or steam) and standard insulation.

FRP STORAGE TANKS

a) Most fibreglass tanks are vertical units fabricated by hand-layup of laminate, as this is the most economical method. Representative costs are as follows:

Up to 2000 I. gal	-	75¢/I. gal.
Around 4000 I. gal.	-	50¢/I. gal.
6000 to 10,000 I. gal	-	40¢/I. gal.

These tanks are significantly cheaper than rubber-lined steel but considerably more expensive than ordinary steel. The volume of fibreglass tanks produced is important to price because tooling costs are so high. Dimensional restraint for shop fabrication is 12' diameter when delivery by truck is intended, and tank height is often 1½ times diameter.

b) Filament-wound FRP tanks using special machines are more expensive than standard hand-layup tanks, but are about three times as strong. They are widely used for <u>horizontal</u> tanks, or for vertical tanks over 20' in height, or wherever the stress in the tank wall becomes relatively high. However, they are rarely used for pressure service above 15 psi, even though Section 10 of the ASME Unfired Pressure Code covers FRP tanks, because a fabricator is required to construct and pressure test to failure the first tank in a batch - an expensive requirement.

c) <u>Resin</u>

Most tanks are of polyester, with vinyl ester being used for the more difficult chemicals such as sodium hypochlorite. Epoxy ester is rarely used.

d) <u>Robustness</u>

There have been complaints that FRP tanks are not sufficiently robust, particularly when moved from one place to another. This is probably more related to the quality of

fabrication than to the material itself. To ensure a good quality tank, one should specify construction to Canadian Govt. Std. 41-GP-22 "Process Equipment, Reinforced Polyester, Chemical Resistant, Custom-Contact Moulded", and a thickness of at least 1/4". (Note that Std. 41-GP-22 permits as low as 3/16" thickness for certain areas of tanks which is thought to be inadequate).

Another point worth noting is that liquid alum is sometimes delivered at very hot temperatures (i.e. over 200° F). At one plant, this caused a vertical FRP Tank to expand to such an extent that the tank bottom dished upwards, popped the anchor bolts, and tilted over. Fortunately, when the solution cooled, the tank settled back into place! Therefore, care should be taken before all loading that tank truck contents are at a reasonable temperature.

OTHER STORAGE TANKS

a) Polyethylene
   - PE tanks are available as free-standing up to 400 I. gal. and as externally reinforced up to 1000 I. gal. These are useful for smaller plants.

b) PVC lined-wood stave
   - Loose PVC liners approx. 40 mil thick are inserted into wood stave tanks. This represents a very economical set-up, and has been used on liquid alum service up to 10,000 I. gal. unit size at certain large treatment plants. The possibility of lining tear and wood rot should be recognized.

c) Rubber-fabric

   i) Bladder tanks are available in unit sizes up to 9000 I. gal. and have been generally used for storing liquid fuels. Their use on corrosive chemicals may be possible, although difficulty with tank insulation and pipe connectors could introduce complications.

   ii) Ground impoundments lined with rubber fabric sheets may find application, but they are generally restricted to very high storage volumes.

d) FRP-lined concrete or steel

   - Monolithic linings of the thermosetting fibreglass reinforced-plastic type with appropriate fillers have been used for lining very large storage tanks such as liquid alum storage at Metro Toronto's Westerly Water Filtration Plant. The substratum or backing may be concrete or steel, the former being the case for Westerly. This lining system has a strong advantage in that it may be applied in the field to large structures, and has broad potential application for corrosive chemicals.

PIPING

For alum or ferric chloride solution service, pipe should be of Schedule 80 PVC, with fittings of extra-heavy moulded PVC, and valves of the PVC ball or diaphragm type. Connections are solvent-welded, with flanges at intervals.

Field assembly should be at ambient temperatures above 50° F. in order to ensure reliable solvent-welding.

Expansion provisions should be carefully and thoroughly provided in the form of offset U-bends or telescopic O-ring expansion joints at regular intervals. The latter requires anchors at changes of direction.

Heat tracing should be by low-density electric tapes, with insulation of the impermeable type such as polyurethane foam or foamed-elastomer.

SUMMARY

LIME TREATMENT

. Provide open channels for main sewage stream rather than closed pipes to facilitate clean-out.

. Avoid cascading of main stream with attendant slime build-up.

. Consider Ni-hard torque-flow pumps for continuous service on abrasive lime sludge.

. Locate lime feeder as close as possible to point of application. When impractical, keep lime slurry transfer piping as simple as possible.

. Consider rubber piping for lime slurry, particularly in smaller sizes.

ALUM OR FERRIC CHLORIDE TREATMENT

. The inert plastics are very suitable for corrosion-resistance.

. Special precautions are required for ferric chloride to avoid staining.

. Use vertical FRP tanks for open (vented) storage, and rubber-lined steel tanks for pressurized storage.

. Use PVC piping systems throughout.

COST, INSTRUMENTATION AND CHEMICAL HANDLING

PHOSPHORUS REMOVAL COSTS

Presented at the Canada-Ontario Agreement
on Great Lakes Water Quality
Phosphorus Removal Design Seminar
May 28-29, 1973

By G. Powell, P. Crawford
Gore & Storrie Limited, Consulting Engineers

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PHOSPHORUS REMOVAL COSTS

INTRODUCTION

In 1970, the International Joint Commission, after intensive study into pollution of the Lower Great Lakes, forwarded to the Governments of Canada and the United States a comprehensive report concerning nutrients in the receiving waters of Lake Erie, Lake Ontario, the international section of the St. Lawrence River and the connecting channels of the Great Lakes. After receipt and careful perusal of this report, the federal and provincial governments set about on a plan of action to implement the recommendations of this report.

The main recommendation of this report which concerns us today is the immediate removal of phosphorus in municipal and industrial effluents to at least one milligram per litre or, in certain cases, 80% reduction of phosphorus and thereafter additional reduction to the maximum extent possible by economically feasible processes.

By the end of 1975, not only those plants in the Lower Great Lakes Basin but also some of those on or tributary to Lake Huron, the Ottawa River watershed and other lakes and rivers will be removing the phosphorus in their effluents.

This is a sizeable undertaking and involves some $2,200,000 in pilot and full-scale studies, an estimated $15,000,000 in capital costs, and some $4,700,000 a year in operating costs.[(1)]

This paper deals with phosphorus removal costs as they pertain to the waste water plants in Ontario.

GENERAL

The quantity of phosphorus in domestic waste waters where phosphorus detergents are allowed is about 3.5 lb. per capita per year. The use of phosphorus-free detergents should lower the quantity of phosphorus in domestic waste waters to about 1.9 lb. per capita per year.[2]

If waste water flow of 100 Imperial gallons per capita per day is assumed, the total phosphorus concentration in domestic wastes would drop from 9.6 to 5.8 milligrams per litre with the use of phosphorus-free detergents. In Ontario the average concentration of total phosphorus in the raw waste water ranges from approximately 5 milligrams per litre to 17 milligrams per litre. Higher concentrations of phosphorus may be expected from industrial wastes such as food industries, laundries, metal cleaning, etc.

REMOVAL METHODS

What then are the methods to remove phosphorus in our waste water effluents? Briefly, the main methods of phosphorus removal are as indicated in Table 1.[3]

Combinations of the various phosphorus removal processes are of course possible, such as biological-chemical, physical-chemical, etc.

CHEMICAL PRECIPITATION

By far the most proven and reliable method for phosphorus removal is chemical precipitation using lime or metallic salts, and it is on this method of removal that our discussion today on costs is based.

Paramount in the consideration of the chemical to be used is, of course, the cost of chemicals. In this paper the approximate average delivered costs of lime, alum and ferric chloride have been used (see Figure 9). Costs are federal and provincial tax excluded as these materials are presently tax exempt.

The use of waste product chemicals for phosphorus removal could be considered. These chemicals include waste pickle liquor from steel cleaning processes, spent calcium carbide lime from acetylene production, and water plant alum sludges. For each situation, however, the suitability must be judged on the basis of content of reactive components, continuous availability, uniformity between shipments, and the presence of excessive amounts of undesirable contaminants such as sequestering agents, grit and free acids. In most cases, the cost benefit is not expected to favour the use of these waste products.

Future availability of phosphorus removal chemicals will, we believe, show preference to those chemicals native to Canada and particularly to Ontario. Increases in energy costs could favour certain chemicals; however, this is a future forecast only.

Reclaiming of the phosphorus removal chemical is also now possible and is being practised in several plants in the U.S.A.

PRELIMINARY INVESTIGATION

Jar testing is normally carried out on the raw sewage and secondary effluent to determine which chemical is most economically suitable.

A test programme normally costs in the neighbourhood of $5,000 and can cost considerably more depending on the complexity of the waste and the treatment plant layout.

The engineer's familiarity with the municipality, its industrial wastes and water supply can provide considerable insight into the scope of the jar testing to be carried out.

After the jar tests have been satisfactorily completed, the data can be analyzed and reported on.

Unfortunately, full-scale studies can normally only be carried out to the extent necessary to confirm the dosage requirements of the chemical determined in the jar testing and the best practical point of application of the chemical. Areas which should also be studied in order that accurate overall costs can be predicted are as shown in Table 2.

The costs of jar testing and full-scale studies in certain cases receive assistance from the government in the form of a rebate. At present a 100 per cent rebate applies to the Lower Great Lakes municipalities.

Other areas at present do not receive any rebate but we understand consideration may be given to a rebate in the future, providing the studies have been run to Ministry standards.

CAPITAL AND OPERATING COSTS

Assuming that the necessary jar and full-scale studies have been completed, the capital and operating costs can be estimated.

LIME

Let us first consider lime as the chosen chemical.

Lime has long been used in water and waste water treatment. It is not an easy chemical to handle and for this reason its reputation has suffered.

Lime is normally applied prior to primary treatment. Its use in biological secondary treatment is not normally possible due to the high pH condition it must create in order to precipitate the phosphorus. Lime can also be used in chemical tertiary treatment and the spent lime can be recalcined. Dosages of approximately 200 milligrams per litre as $Ca(OH)_2$ normally make the application of lime economically attractive.

Lime can be delivered in bag form, in shipments of 10 tons or more. Storage for a 10-ton delivery is approximately 175 square feet.

For a one million gallon per day plant utilizing one ton of bagged lime per day, a chemical facility would be laid out as indicated in Figure 1, and the chemical facility costs are as follows:

COSTS FOR BAGGED LIME FACILITY TO
SERVE A 1 MGD WASTE TREATMENT PLANT

Capital Costs

1.	Chemical Building including bag loading hopper, storage hopper, feeder, dissolver and piping	$34,300	
	Construction Costs	34,300	
	Engineering and Contingencies @ 15%	5,145	
	Total Capital Costs	$39,445	
	Annual Amortized Capital Cost @ 10%		$ 3,945

Operating Costs

1.	Operator $4.00/hour @ 6 hours/day	$ 8,750	
2.	Laboratory Technician $4.00/hour @ ½ hour/day	730	
3.	Maintenance - Allow	1,000	
4.	Power Costs 3 HP @ $60/HP/year	180	
5.	Water Costs	120	
6.	Chemical Costs 1 ton/day @ $25/ton	9,125	
	Annual Operating Costs		19,905
	Total Annual Costs		$23,850

Cost per Million Gallons = $65.00

Cost per Capita per Year = $2.40

Lime can also be delivered in bulk in shipments of 20 tons or more. Silo type storage is normally provided for about 30 tons of lime. A suggested facility is as shown in Figure 2.

For a one million gallon per day plant utilizing one ton of bulk hydrated lime per day, the chemical facility costs are as follows:

COSTS FOR A BULK LIME DRY STORAGE FACILITY
FOR A 1 MGD WASTE TREATMENT PLANT

Capital Costs

1.	Chemical Building including silo and feed equipment and foundations	$35,000	
	Construction Costs	35,000	
	Engineering and Contingencies @ 15%	5,250	
	Total Capital Cost	$40,250	
	Annual Amortized Capital Cost @ 10%		$ 4,025

Operating Costs

1.	Operator $4.00/hour @ 4 hours/day	$ 5,840	
2.	Laboratory Technician $4.00/hour @ ½ hour/day	730	
3.	Maintenance	2,000	
4.	Power 3 HP @ $60/HP/year	180	
5.	Water Costs	120	
6.	Chemical Costs 1 ton/day @ $23/MG	8,400	
	Annual Operating Costs		17,270
	Total Annual Costs		$21,295

Cost per Million Gallons = $58.40

Cost per Capita per Year = $2.10

For a one million gallon per day plant utilizing bulk delivery of lime and stored as a 25 per cent liquid slurry of lime and not dry in a silo, costs are as follows:[4]

COSTS FOR A LIQUID LIME SLURRY FACILITY
FOR A 1 MGD WASTE TREATMENT PLANT

Capital Costs			
1.	Chemical tanks including pumps, mixers and piping	\$54,800	
	Construction Costs	54,800	
	Engineering and Contingencies	5,200	
	Total Capital Costs	\$60,000	
	Annual Amortized Capital Cost @ 10%		\$ 6,000
Operating Costs			
1.	Operator \$4.00/hour @ 4 hours/day	\$ 5,840	
2.	Laboratory Technician \$4.00/hour @ ½ hour/day	730	
3.	Maintenance	2,000	
4.	Power 15 HP @ \$60/HP/year	900	
5.	Water Costs	180	
6.	Chemical Costs 1 ton/day @ \$23/MG	8,400	
	Annual Operating Costs		18,050
	Total Annual Costs		\$24,050

Cost per Million Gallons = \$66.00

Cost per Capita per Year = \$2.40

In the preceding cost estimates, no costs have been considered for rapid mixing or flocculation facilities. We believe sufficient mixing and flocculation will take place in an aerated grit tank, in the inlet channels, and during primary settling.

At an approximately 250,000 gallons per day waste treatment facility, the total annual costs for a bagged lime facility and a bulk lime facility are equal.

The use of bagged lime we believe is preferred at about the 250,000 gallon per day plant size and smaller as the bag handling is reasonably low (i.e. 10 bags per day). In dry storage, bags of hydrated lime may be stored for periods of at least 6 months without encountering serious deterioration.

Plants of greater than 250,000 gallons per day would favour a bulk lime handling facility using hydrated lime. Only in extremely large installations is consideration given to quick-lime. A slight saving in chemical cost may result in large plants based on more favourable freight charges for quick-lime versus hydrated lime.

These costs must be balanced against more complex slaking equipment and higher operational costs.

A liquid slurry facility, although costing more, allows the use of waste carbide lime and in certain cases this could be economically advantageous.

Additional plant maintenance may also be expected in the following areas:

(1) scaling
(2) wear

Recycling of seeded lime sludge is claimed to prevent scale problems. Wear, however, will be a problem in sludge collecting, piping and pumping equipment. Heat exchanger and digestion tank scaling may also be a problem if anaerobic digestion is practised. Only actual operating experience will allow accurate assessment of this type of maintenance costs.

B.O.D. and suspended solids removal are enhanced by the addition of lime prior to primary settling. Normally in primary treatment, B.O.D. and suspended solids removal of 30 and 50 per cent respectively are experienced. With the addition of lime, removals of B.O.D. and suspended solids up to 50 and 70 per cent respectively may be expected.

The increased B.O.D. removal in primary treatment allows the secondary aeration tanks to be reduced in size, or in the case of an existing aeration tank to extend its capacity.

For a one m.g.d. plant with a raw sewage B.O.D. of 200 mg./l., the estimated cost of an aeration tank loaded at 50 lb. of B.O.D. per thousand cubic feet per day is $140,000.

For a one m.g.d. plant with similar raw sewage strength and using lime in the primary tank, the cost of the aerator at a similar B.O.D. loading is estimated at $100,000.

The capital cost saving is approximately 30 per cent. Operating costs will also be lower for the aerator. The power cost saving because of lower air consumption is estimated at $1,150 per year.

Similarly, the amount of waste activated sludge synthesized is reduced by approximately 30 per cent.

Overflow rates in the primary settling tanks need not be reduced as is the case with metallic salts. Overflow rates

in the range of 800 to 1100 gallons per square foot per day may be used.[4]

Digestion, although originally thought questionable because of the pH condition of the sludge, has proved feasible at Newmarket where a significant drop in pH was experienced without resolubilizing the phosphorus.[4]

Sludge quantity does not appear to increase; however, sludge concentrations are much higher.

Land application of digested lime sludge was also carried out at Newmarket and alfalfa was being grown without apparent adverse effects.

For larger plants where economics indicate trucking of liquid sludge to be excessive, dewatering and incineration of the lime sludge is attractive.

Lime primary sludge dewaters well by either vacuum filter or centrifuge to a sludge cake of 75 per cent moisture content or less and at filter yields of over 5.0 lb. dry solids per square foot per hour. Sludge chemical conditioning costs also are lower than normal.[5]

Recalcining of the raw primary limed sludge has not been very successful due to the interference of deleterious material in the primary sludge. In tertiary treatment the amount of deleterious material in the sludge is considerably reduced and recalcining is possible.

Let us take a brief look at phosphorus removal using lime applied just prior to tertiary treatment. Obviously increased capital costs will be incurred due to the need for rapid mixing, flocculation and settling tanks, and possibly recarbonation for pH correction.

At South Lake Tahoe, phosphorus removal is a tertiary step. Lime in the amount of 400 to 500 mg./l. as CaO is applied with 0.1 to 0.3 mg./l. of polymer also added to improve clarification. Phosphorus removal is typically 95 per cent with effluent ranging between 0.07 and 0.2 mg./l. total phosphorus.[6]

Phosphorus removal and lime dewatering and recalcining costs at South Lake Tahoe are reported as follows:[6]

COST OF TERTIARY TREATMENT AT SOUTH LAKE TAHOE FOR PHOSPHORUS REMOVAL

<u>Capital Costs</u> (per million gallons)(1973 costs)		
1. Lime Coagulation and Sedimentation	$17.40	
2. Lime Sludge Dewatering	5.30	
3. Lime Sludge Recalcining	18.80	
Total Capital Costs		$ 41.50
<u>Operating Costs</u> (per million gallons)		
1. Lime Coagulation and Sedimentation	$37.60	
2. Lime Sludge Dewatering	7.80	
3. Lime Sludge Recalcining	38.30	
Total Operating Costs		83.70
Total Cost		$125.20

Cost per Capita per Year = $4.60

At South Lake Tahoe, recalcining and dewatering costs are indicated to be \$29 per ton as CaO. Lime at present is only used approximately three times, however, before being considered spent.

Based on the cost of purchased lime at Lake Tahoe, it would also appear that the reasons for recalcining are mainly for research and due to high sludge disposal costs.

Tertiary lime treatment, however, is the only method offering a proven method of recovery of the treatment chemical, and at present this cannot be said of aluminum or iron salts.

For very high degrees of phosphorus removal, tertiary lime treatment appears as an excellent choice. Phosphorus removal to less than 0.1 mg./l. can be achieved and secondary benefits such as further removal of B.O.D., suspended solids, turbidity and colour are possible.

The estimated costs for lime tertiary treatment are approximately 2 to 3 times the total cost per million gallons for phosphorus removal using lime applied prior to primary treatment.

The degree of phosphorus removal presently being requested by the Ministry does not, we believe, warrant tertiary treatment using lime. However, when low B.O.D. and suspended solids residual are also required this could very well be the most economical method.

METALLIC SALTS

Metallic salts such as alum and ferric chloride are enough alike in both application and the chemical feed facility that in this paper we will deal with these chemicals as being identical as far as required facilities for storage and application are concerned.

Alum and ferric chloride are both tri-valent acid salts which, unlike lime, can normally be used simultaneously with biological treatment.

Usually, dosages of approximately 100 milligrams per litre for alum and 15 milligrams per litre for ferric chloride as Fe normally make the application of alum and ferric chloride economically attractive.

They can be supplied either in dry or liquid solution form. Liquid is, we believe, the preferred form and facility costs will be based on liquid chemical.

Liquid chemical is delivered in tank truck shipments of 3,000 gallons or more. Storage of chemical should be for at least 6,000 gallons and normally a two week supply is stored.

A typical facility for either alum or ferric chloride is shown in Figure 3.

For a one million gallon per day treatment facility using $30 of chemical per million gallons, the chemical facility capital and operating costs are as follows:

COST FOR LIQUID METALLIC SALT FACILITY
TO SERVE A 1 MGD WASTE TREATMENT PLANT

Capital Costs

1.	Equipment costs including outdoor insulated storage tanks and feed pumps	$15,500	
2.	Tank foundations and pipe chase	4,000	
3.	Installation costs and associated piping	6,000	
	Construction Costs	25,500	
	Engineering and Contingencies @ 15%	3,825	
	Total Capital Costs	$29,325	
	Annual Amortized Capital Costs @ 10%		$ 2,933

Operating Costs

1.	Operator $4.00/hour @ ½ hour/day	$ 730	
2.	Laboratory Technician $4.00/hour @ ½ hour/day	730	
3.	Maintenance-Allow	300	
4.	Power Costs ½ HP @ $60/HP/year	30	
5.	Chemical Costs Allow $30/million gallon	10,950	
	Annual Operating Cost		$12,740
	Total Annual Cost		15,673

Cost per Million Gallons = $43.00

Cost per Capita per Year = $1.57

As with lime, to date we have not found it necessary to consider rapid mixing and flocculation tanks because existing facilities have provided adequate mixing and flocculation.

Operating and maintenance problems using metallic salts have been minimal.

B.O.D. and suspended solids removal are increased by the addition of metallic salts prior to primary settling and aeration costs may be reduced. Capital and operating cost savings similar to those mentioned for lime are possible.

Application of metallic salts to the activated sludge mixed liquor prior to final settling have in most cases yielded a lesser chemical dosage than when added prior to primary treatment.

At the North Toronto plant in Metropolitan Toronto, with an influent P of 5.0 milligrams per litre, a ferric chloride dosage of 13.4 milligrams per litre of Fe applied prior to primary treatment yielded a phosphorus content in the final effluent of 0.65 mg./l., and when applied to the aeration tank mixed liquor yielded a phosphorus content in the final effluent of 0.40 mg./l. Presently, a ferric chloride dosage of 8.5 milligrams per litre, that is a chemical cost of $13.60 per million gallons treated, yields a phosphorus content in the final effluent of less than 0.4 milligrams per litre.

Chemical addition to the mixed liquor results in a build-up of a reservoir of still partly reactive chemical in the secondary sludge system which helps to buffer the effects of variations in the phosphorus feed to the system. From a capital cost point of view this is favourable in that it reduces the need for flow pacing of the chemical feed pumps. The reactive capacity of the retained chemical was demonstrated in two particular recent studies where it was found that phosphorus continued to be removed for approximately three days

after the chemical feed system was shut off.

In order to maintain a proper food to micro-organism ratio in the aeration tank, return sludge rates normally must be increased to at least 100 per cent of the aerator influent flow.[7]

Waste sludge rates also are indicated to increase.

To provide a one m.g.d. plant with 150% of average plant flow return sludge pumping capacity and 3% of average plant flow waste sludge pumping capacity, the capital cost would be estimated at around $3,000 higher than for normal design, and operating costs including amortization of capital would be $540 per year higher.

It is indicated from full-scale studies that final tank overflow rates should also be reduced from an average design rate of 600 gallons per square foot per day to 450 gallons per square foot per day. For a one m.g.d. plant the additional capital cost is estimated at $38,500.

Unlike lime, raw sludge volumes have been reported to increase considerably using metallic salts. Increases in raw and digested sludge flow and concentration have been reported as high as 50 per cent.

At North Toronto, statistical analysis of raw and digested sludge flows and concentrations indicate sludge increase to be negligible. This analysis is based on 14 months of sludge data prior to phosphorus removal and 25 months of data during phosphorus removal.

Raw sludges produced as a result of phosphorus treatment with metallic salts will digest. Digester loadings in the neighbourhood of 0.08 lb. of volatile solids per cubic foot of digester volume per day are at present operating well with good gas production.

Higher digester loadings may create problems; however, this still must be proven out through plant scale studies.

Digester heating equipment must be increased in capacity due to the increased sludge volumes. For a one million gallon per day waste treatment plant the increased cost is estimated at \$400. Sufficient sewage gas will, we believe, be produced and no extra fuel costs are considered.

Sludge disposal costs may similarly increase and for a one m.g.d. plant the additional sludge haulage cost is estimated at \$1,640 per year based on \$1.50 a yard for sludge haulage and a 20 per cent sludge increase.

Application of the sludge on the land has not to date caused problems. The build-up of heavy metals precipitated by the lime and metallic salts may, however, eventually create problems.(5)

In certain cases, economics and disposal restrictions will dictate the dewatering of phosphorus sludges. Vacuum filters and centrifuges have successfully dewatered phosphorus sludges; however, costs may be considerable.

At North Toronto where a digested phosphorus iron sludge is dewatered, solids content has decreased from 24 per cent to 20 per cent solids. Filter yields average 4.45 lb. of dry solids per square foot per day and chemical costs for sludge conditioning approximately \$11.00 per ton dry solids. Solids capture was significantly improved.

At the West Windsor Sewage Plant, the raw phosphorus alum sludge was dewatered to 19 per cent solids. Prior to alum addition it dewatered to 31 per cent solids. Filter yields dropped from 11.3 lb. per square foot per day to 5.8 lb. per square foot per day and chemical costs rose from \$3.10 per ton dry solids to \$9.50. Filter recoveries were considerably poorer.(8)

At North Toronto no appreciable change in chlorine consumption can be claimed.

Metallic salt addition to stabilization lagoons has been successful in removing phosphorus in the lagoon effluent to one milligram per litre of phosphorus or less.

This was demonstrated by the Ministry recently at Aylmer, Arthur and Beaverton.

Costs are mainly chemical and mixing costs and are estimated at $115.00 per million gallons or $4.20 per capita per year based on a chemical dosage of 200 milligrams per litre of alum and a flow of 100,000 gallons per day.

Spray irrigation, in certain cases, may be required where nutrients have seriously affected the water quality of a river or lake.

Based on the costs for spray irrigation encountered at Listowel, the average total cost per million gallons, including leasing of land, is estimated at $233 per million gallons or $8.50 per capita per year.[1]

A similar high cost is indicated for Shelburne where the total cost for spray irrigation per million gallons is estimated at $356 and the cost per capita per year $13.00.[4]

In considering these costs, it must be realized that the degree of treatment removes some 95 per cent of the total phosphorus, 80 per cent of the Kjeldahl nitrogen and 99 per cent of nitrates.

FINANCING

As mentioned previously, pilot and full-scale studies in the Lower Great Lakes receive a 100 per cent subsidy providing they are done to the requirements of the Ministry.

Capital costs for phosphorus facilities can receive assistance from Central Mortgage and Housing in the form of a long term loan, 25 per cent of which is forgivable.

The Federal winter works programme also gives an opportunity for similar savings if the construction of the facility can be incorporated into the programme.

Operating costs must of course be financed from the annual works budget. Possible savings in chemical costs in the case of metallic salts can be realized by tendering for both chemicals and leaving the choice of chemical to economic evaluation.

In the case of alum, the purchasing of the alum supply jointly for both water and sewage plants could realize a further saving.

Sewer use by-laws should be amended to regulate the discharge of phosphorus in industrial effluents and a suitable surcharge should be applied to those industries failing to meet the by-law.

DISCUSSION

The dosage of lime required for phosphorus removal is independent of the phosphorus concentration in the sewage. Since the phosphorus removal mechanism depends on pH, the dosage is actually a function of alkalinity. Since alkalinity is relatively uniform in Ontario, the dosages are also uniform at approximately 200 milligrams per litre as $Ca(OH)_2$.

On the other hand, metallic salts react stoichiometrically with the phosphorus and hence the dosage is a function of phosphorus concentration. The theoretical molar ratio, that is, the number of ferric or aluminum ions required to combine with one phosphate ion, is one. However, as a result of competing reactions the molar ratio is often greater than one. Usually, the closer the dosing point is to the head of the plant, the higher the molar ratio. For aluminum, typical molar ratios are from 1.5 to 2, while for iron the ratios range from less than one to as high as 7.5.[3]

In jar tests carried out at the Kingston Sewage Treatment Plant the molar ratios for alum ranged from 1.3 to 2.5 while for iron the range was 1.1 to 2.1. However, in all test work carried out on a full-scale basis the resulting molar ratios have been less than that found in the jar testing.[1]

In Ontario, the average incoming phosphorus concentration is about 10 milligrams per litre, although some may be considerably less, such as North Toronto at 5 milligrams per litre.

By knowing the incoming phosphorus concentration and the molar ratio, the chemical cost per capita per year can be found using Figure 4. This graph is based on a delivered chemical cost of 6.5¢/lb. for ferric chloride and 3¢/lb. for alum.

Based on chemical costs of \$23 per million gallons for lime primary treatment, \$46 per million gallons for lime tertiary treatment and \$30 per million gallons for metallic salts, the total annual costs per million gallons versus the treatment plant capacity can be graphically represented as shown in Figures 5, 6 and 7.

Where chemicals are added prior to primary treatment or simultaneously with secondary treatment, operating costs including chemical costs are by far the most important economic consideration.

Based on a one million gallon per day facility, the percentage annual costs can be illustrated as shown in Figure 8.

In addition, costs and cost savings may occur due to the effect of the phosphorus removal chemical on the waste treatment processes as indicated hereinbefore. Most significant are sludge disposal costs, hydraulic overflow rates in the settling tanks and possible aeration tank savings.

SUMMARY

The designers' familiarity with the effect of the phosphorus removal chemicals on the treatment processes is most important in order that the three phosphorus removal chemicals can be fairly evaluated.

Insufficient data is presently available for accurate costs on phosphorus sludge disposal and the effect of lime on biological treatment at elevated pH's.

As effluent standards are made more stringent to safeguard our waters, treatment costs will increase.

With higher and more sophisticated degrees of treatment, a better understanding of the operation and the economics of the treatment processes involved will no doubt result.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the assistance of Mr. M. Yatabe, P.Eng., of Gore & Storrie Limited, the Municipality of Metropolitan Toronto and the Ontario Ministry of the Environment who have aided in the preparation of this paper.

REFERENCES

(1) Personal communication with Ministry of the Environment.

(2) Hetling, Carich. "Phosphorus in Wastewater", Water and Sewage Works, 120, 2, 59 (1973).

(3) Nesbitt. "Phosphorus Removal State of the Art", W.P.C.F., 41, 701 (1969).

(4) Black, Rupke. "Phosphorus Removal - The State of the Art", Water and Pollution Control, 110, 7 (1972).

(5) Black. "Treatment and Disposal of Chemical Sewage Sludge", Proceedings of Technical Seminar on Sewage Sludges' Conditioning, Dewatering and Disposal, November 16, 1972.

(6) Evans, Wilson. "Capital and Operating Costs - AWT", W.P.C.F., 44, 1, 1 (1972).

(7) Personal communication with E. A. Thomas, Universitat und Kantonales Laboratorium, Zurich, Switzerland.

(8) Department of Works, Windsor. "Phosphorus Removal Studies at West Windsor Sewage Treatment Plant".

APPENDIX

Table 1

ESTIMATED COSTS OF PHOSPHORUS REMOVAL

Precipitant	Process Scheme	Plant Size (mgd)	Cost $/cap./yr.
biological	activated sludge, acid stripping (luxury uptake)	8.3	2.60
metallic salt	tertiary treatment	8.3	2.60
metallic salt	tertiary treatment + filtration	8.3	5.25
lime	tertiary treatment + filtration	3.3-6.3	5.90
metallic salt	tertiary treatment + filtration + lakes	2.5	10.00
metallic salt	tertiary treatment + filtration	2.1-3.3	5.90
ion exchange	tertiary treatment	0.83-8.3	3.90
metallic salt	batch lagoon treatment	0.12	4.20
biological	spray irrigation	1.2	8.50

Table 2

SUGGESTED AREAS OF FURTHER INVESTIGATION FOR COST EVALUATION

1. Sludge Characteristics

   (a) quantities
   (b) concentrations
   (c) treatability
   (d) land application

2. Hydraulic Parameters

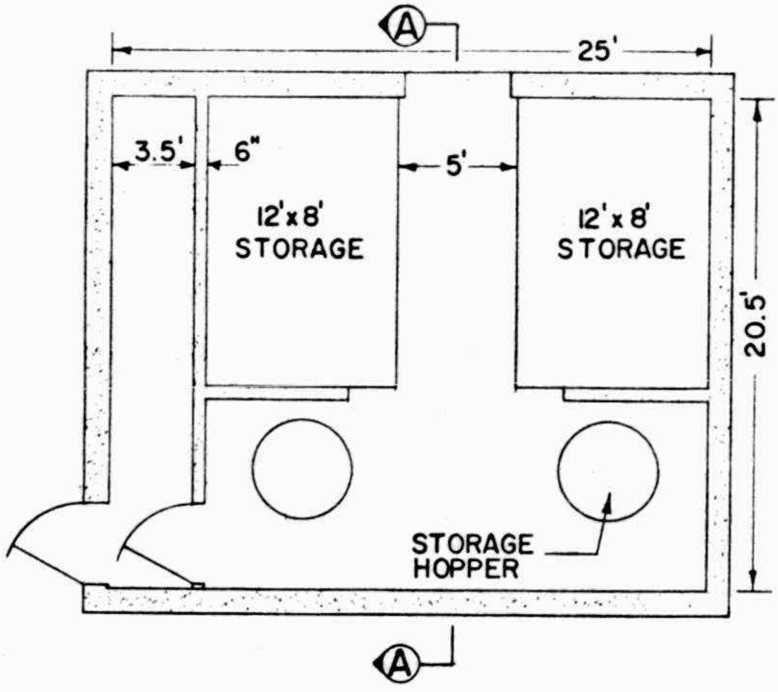
   (a) tank overflow rates
   (b) sludge pumping costs

3. Biological Parameters

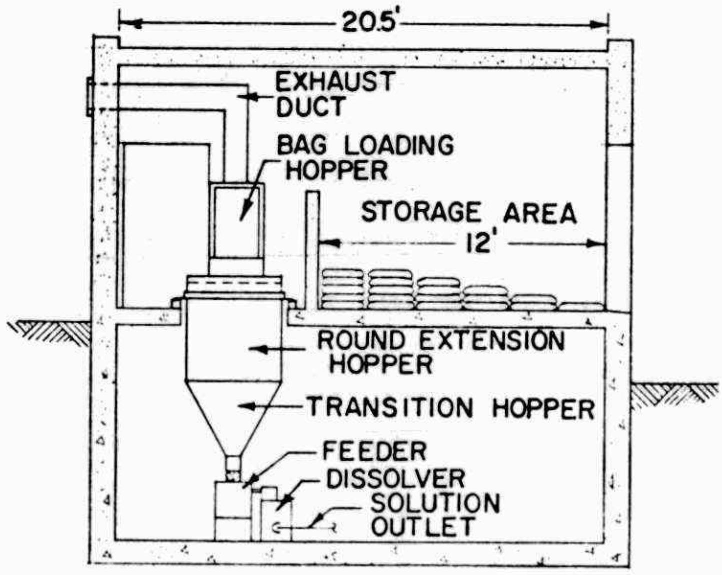
   (a) aeration tank sizing
   (b) activated sludge pumping requirements
   (c) blower or mechanical aerator requirements
   (d) digestion requirements
   (e) pH parameters

4. Miscellaneous Considerations

   (a) digestion tank heating
   (b) chlorine consumption
   (c) maintenance requirements



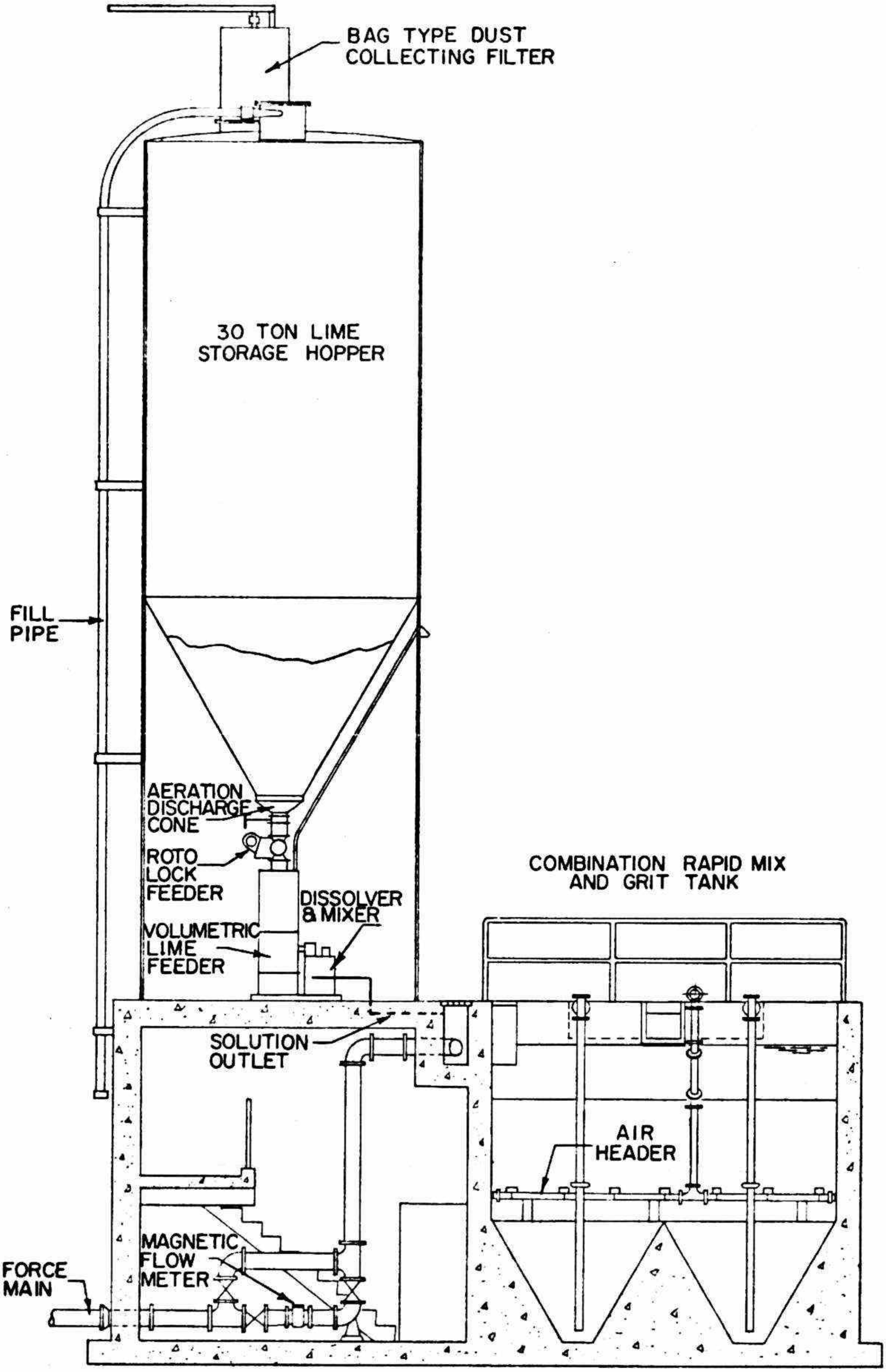
PLAN



A SECTION

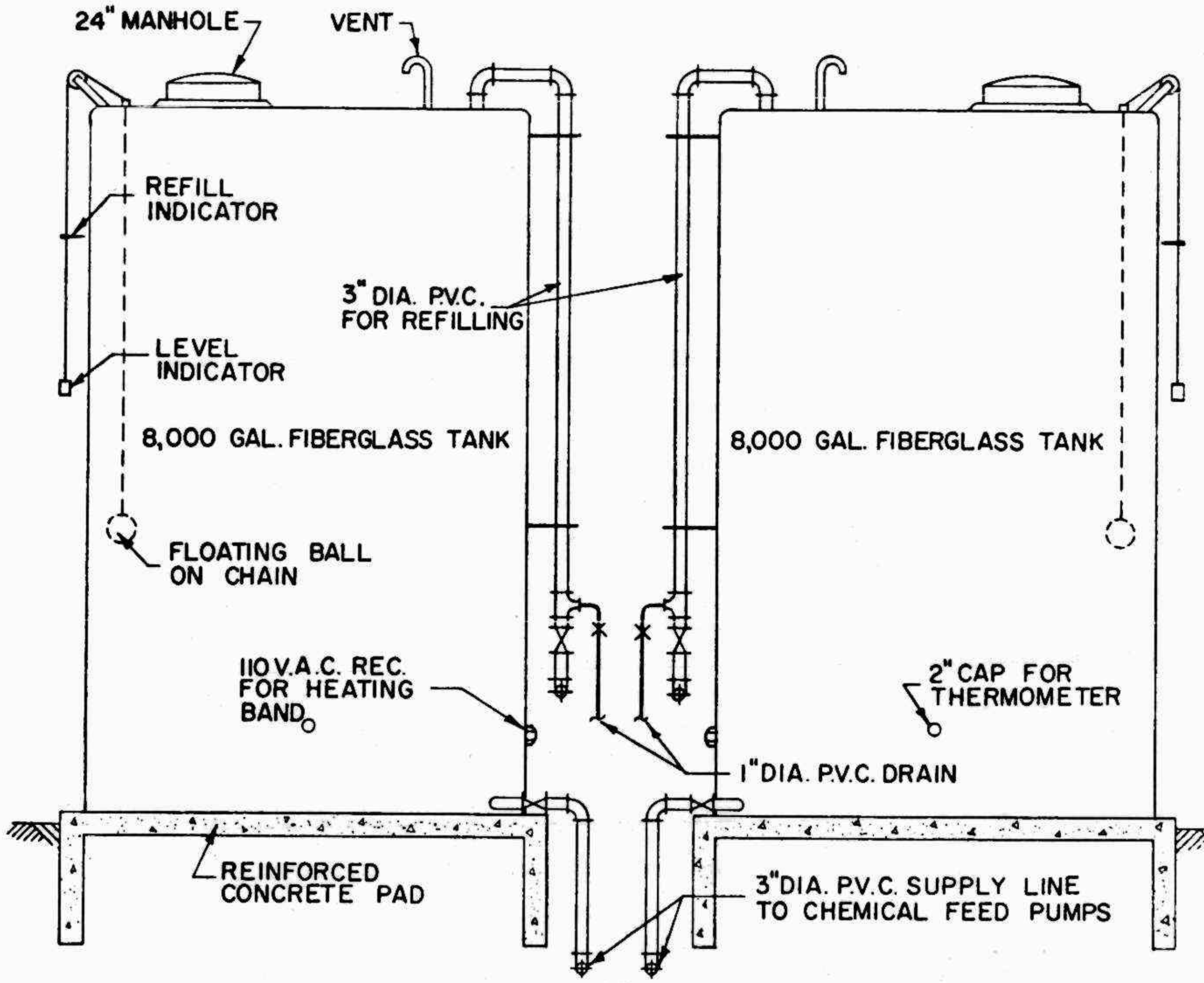
BAGGED LIME FACILITY

FIGURE I



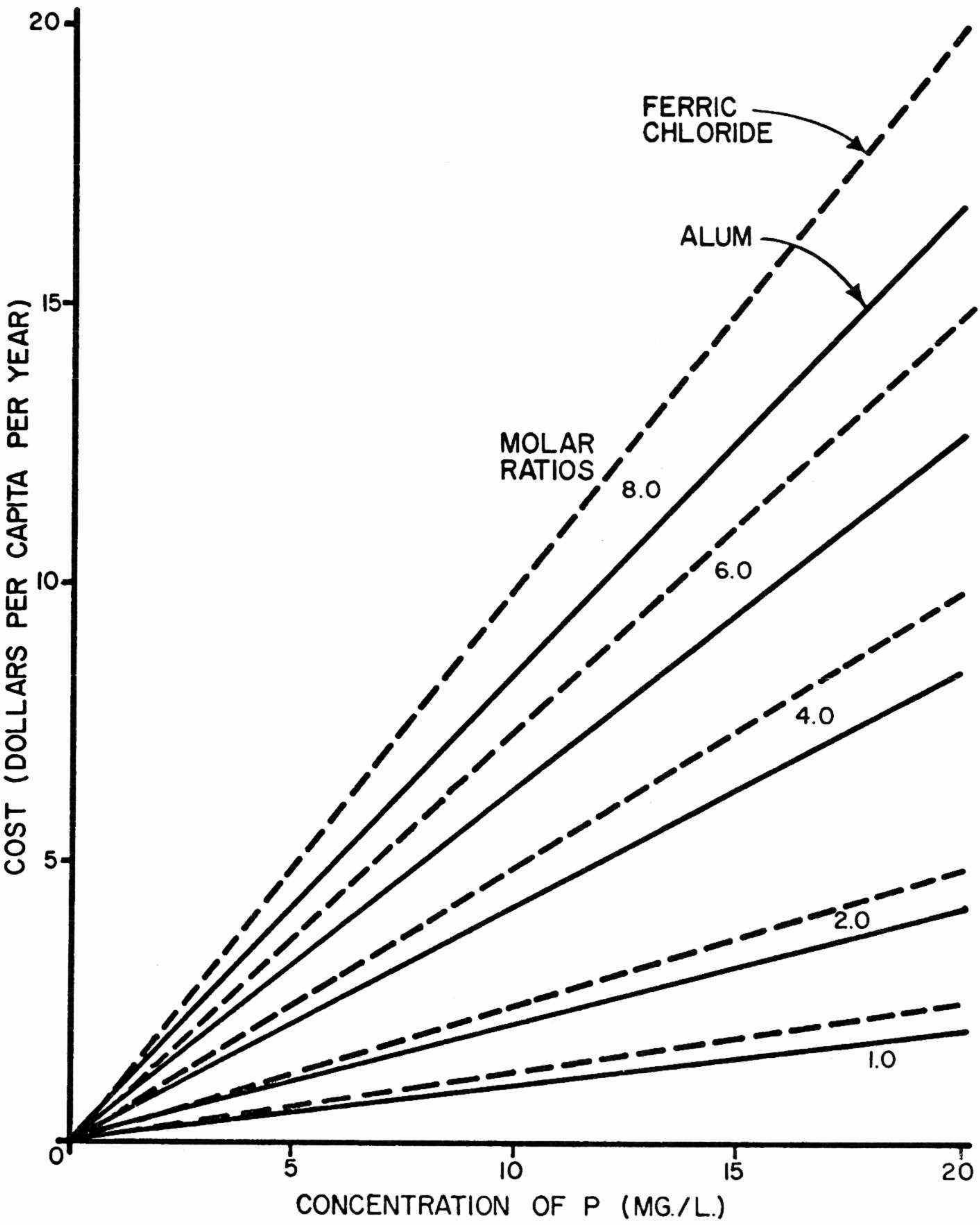
BULK LIME FACILITY

FIGURE 2



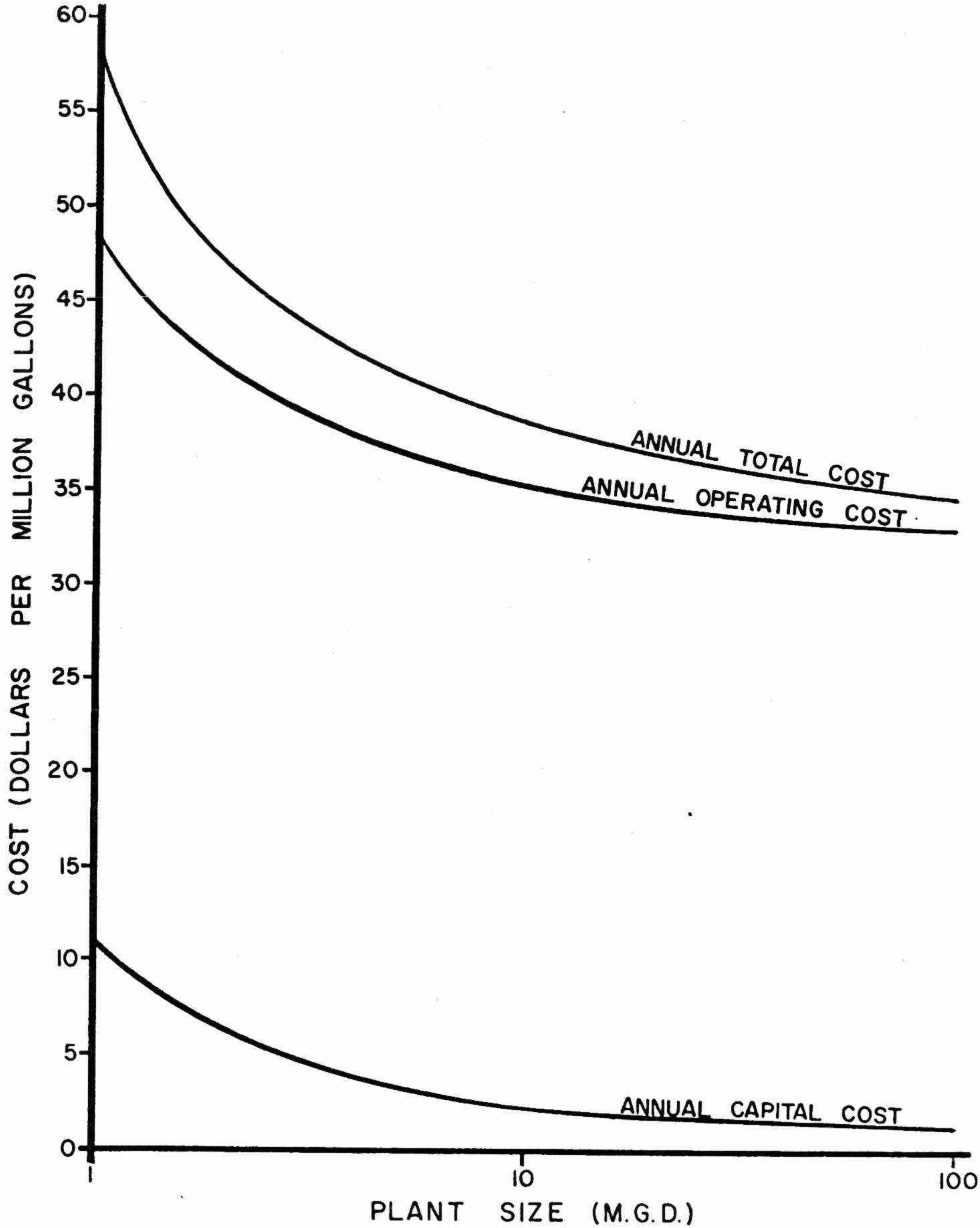
LIQUID METALLIC SALT FACILITY

FIGURE 3



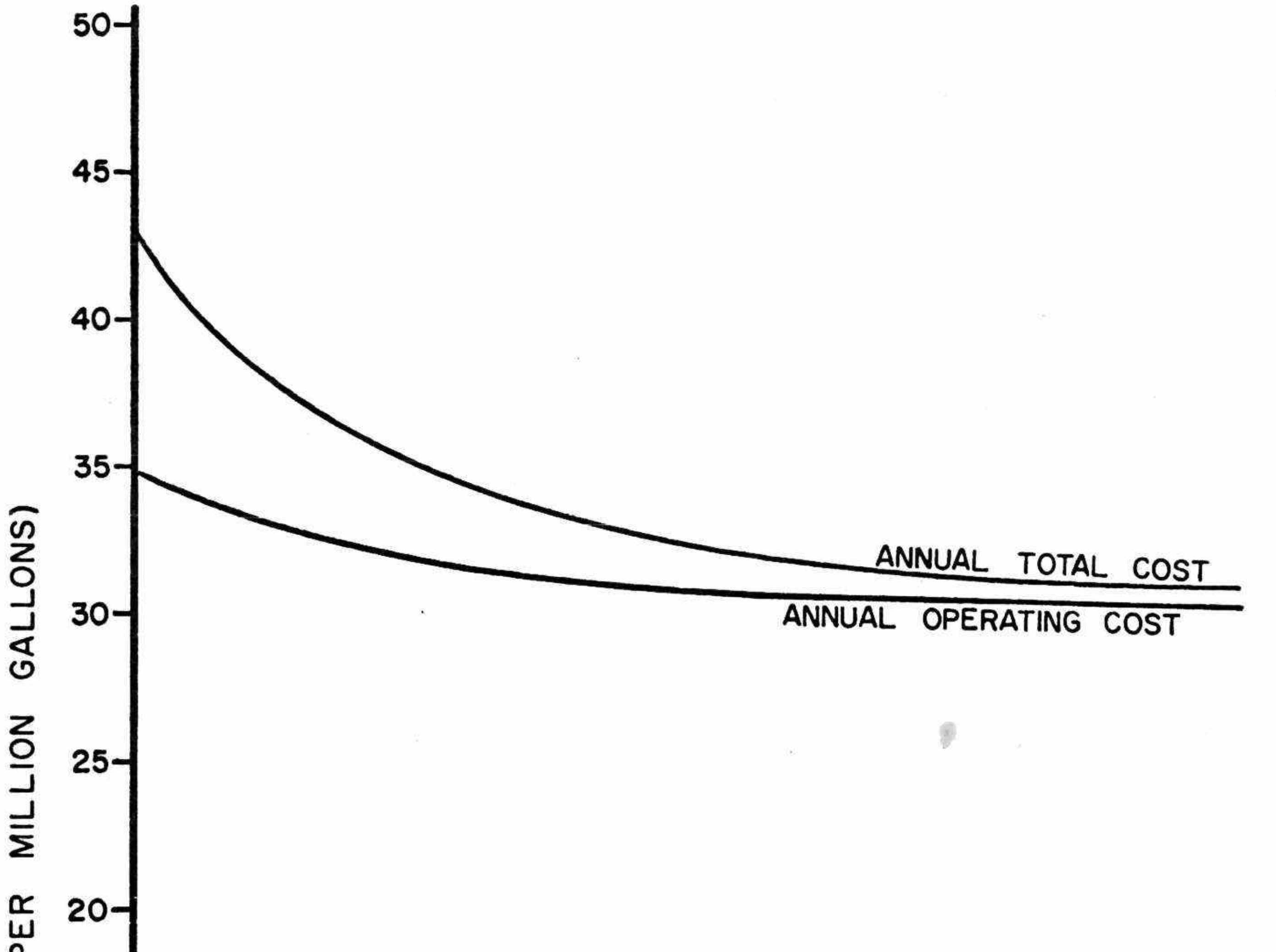
COST VS. CONCENTRATION OF P
FOR METALLIC SALTS

FIGURE 4



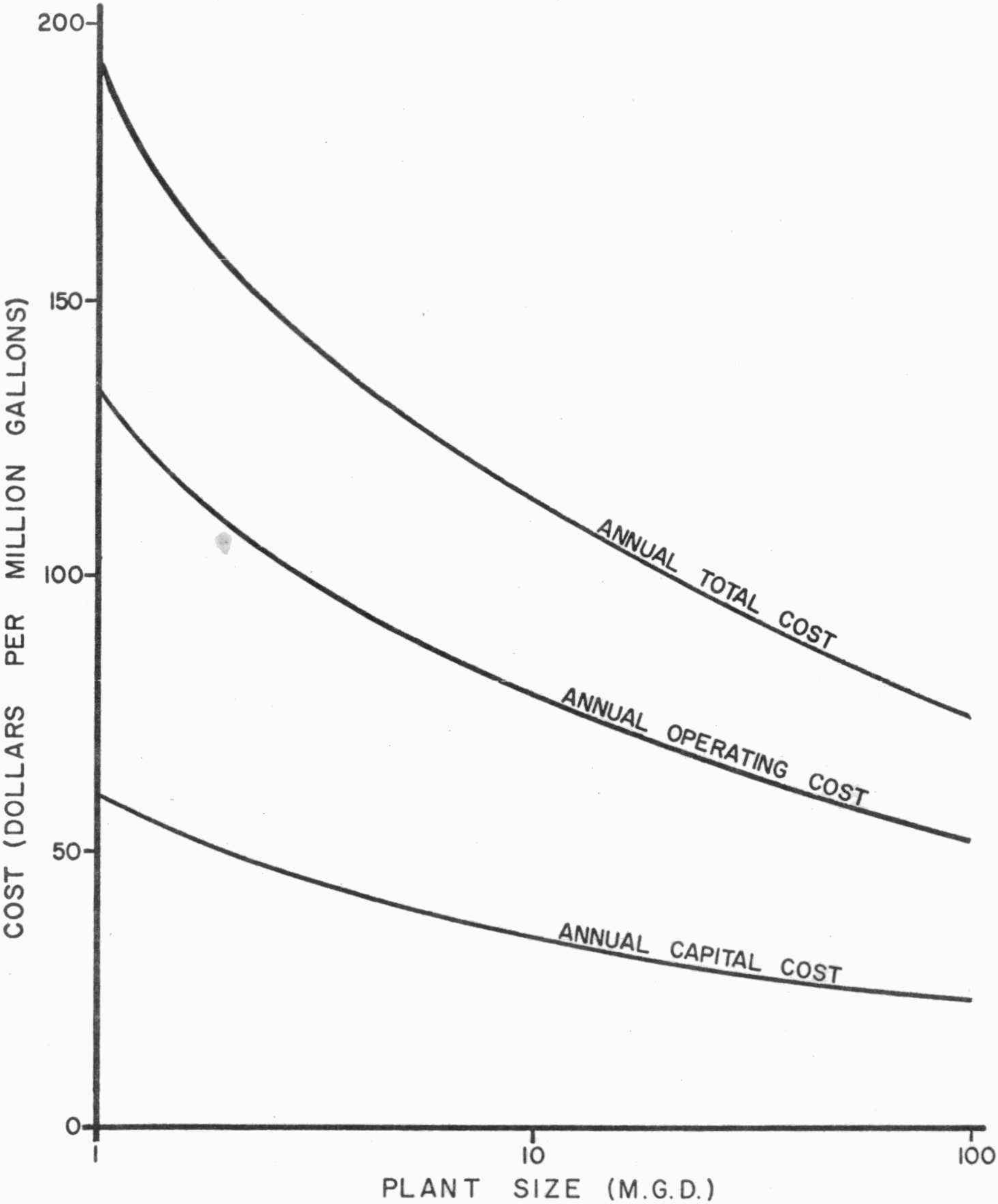
COST OF LIME PRIMARY TREATMENT

FIGURE 5



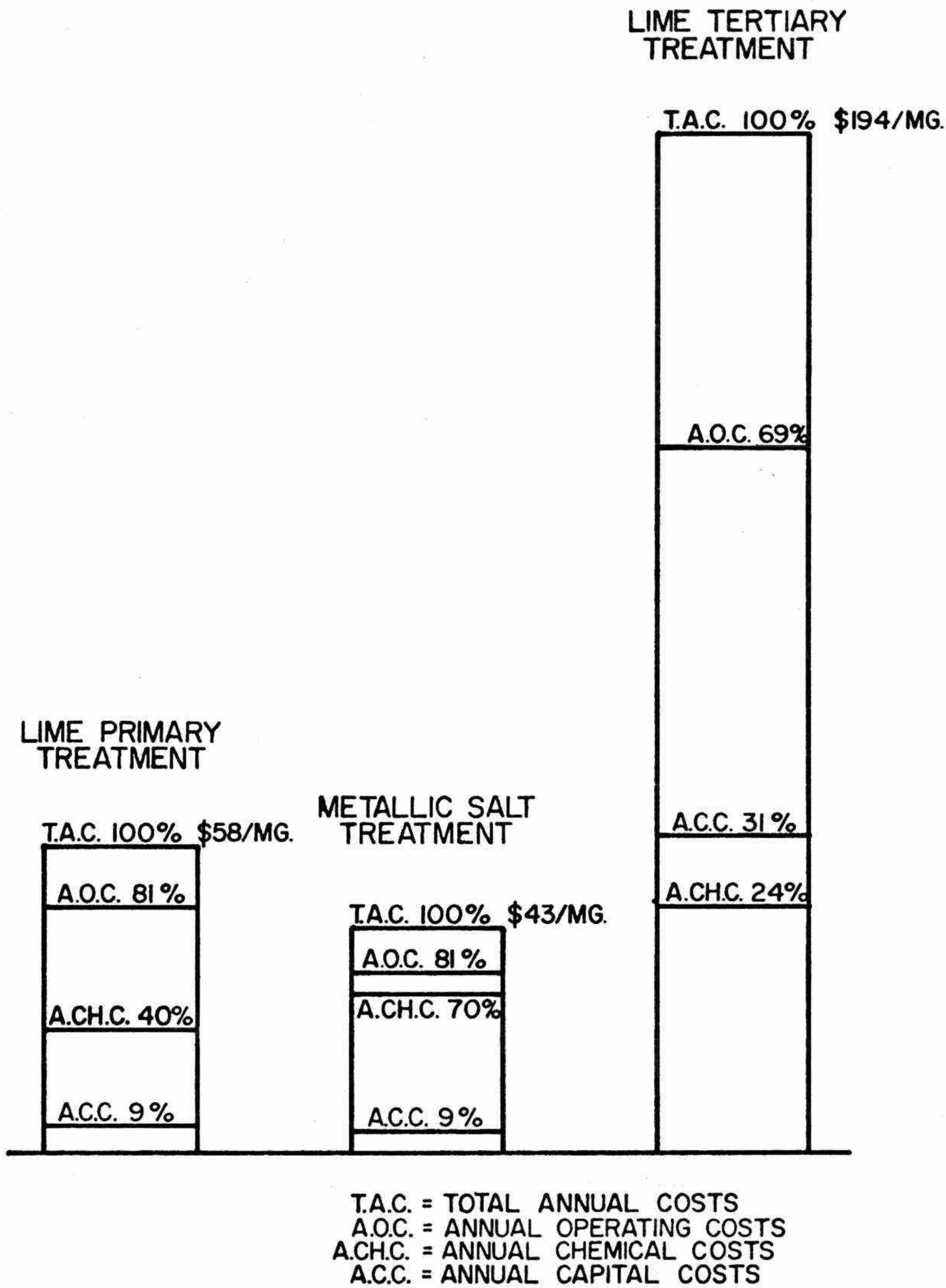
COST OF METALLIC SALT TREATMENT

FIGURE 6



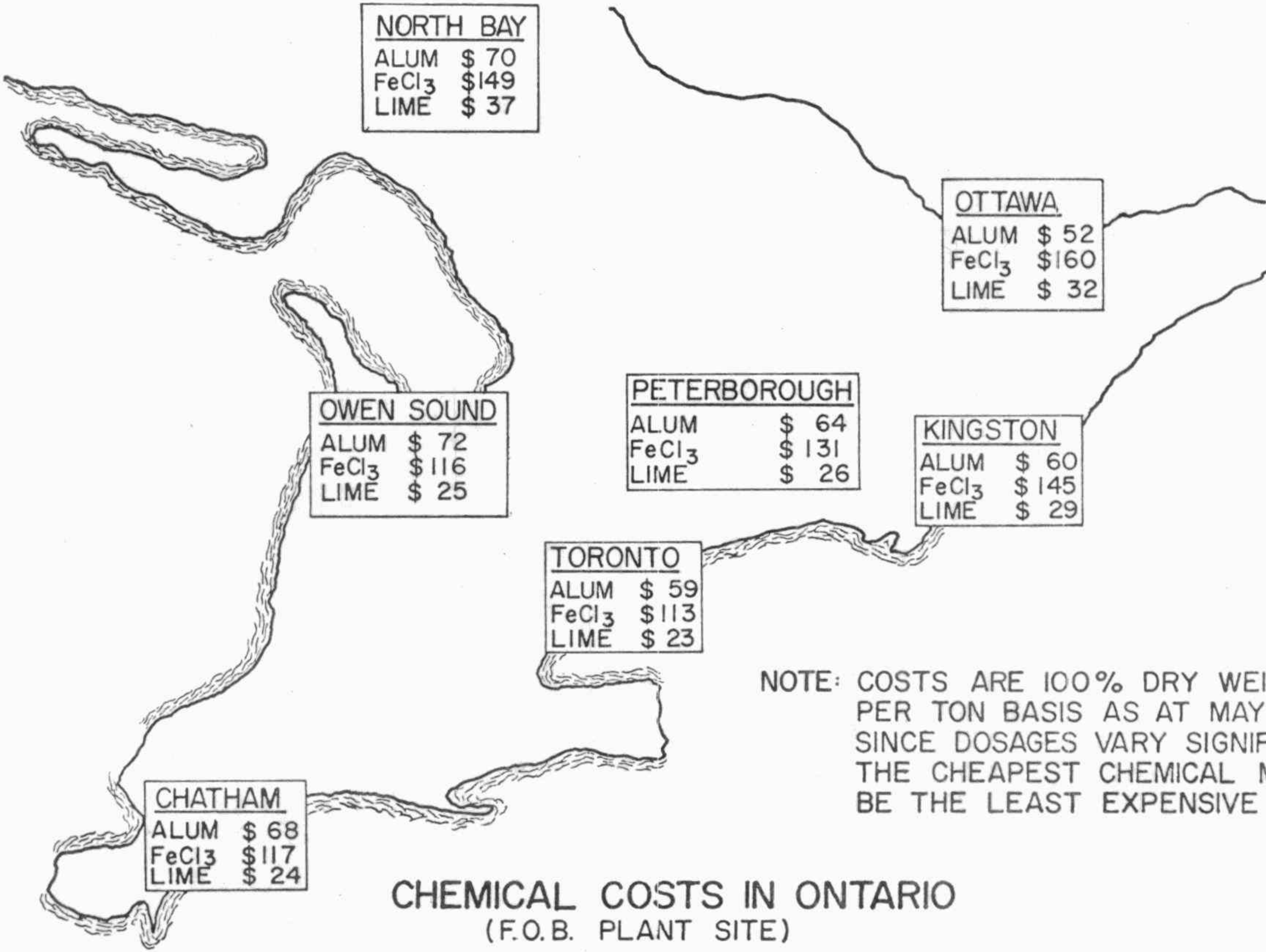
COST OF LIME TERTIARY TREATMENT

FIGURE 7



PERCENTAGE ANNUAL COSTS
FOR 1 M.G.D. PLANT CAPACITY

FIGURE 8



NOTE: COSTS ARE 100% DRY WEIGHT PER TON BASIS AS AT MAY 25, 1973. SINCE DOSAGES VARY SIGNIFICANTLY, THE CHEAPEST CHEMICAL MAY NOT BE THE LEAST EXPENSIVE TO USE.

CHEMICAL COSTS IN ONTARIO
(F.O.B. PLANT SITE)

FIGURE 9

Instrumentation and Automatic Control of Phosphorus Removal Processes

Dr. Stacy L. Daniels
Environmental Control Systems
The Dow Chemical Company
2020 Dow Center
Midland, Michigan 48640

Table of Contents

INTRODUCTION

Many species of aquatic photosynthetic organisms utilize water-soluble anions of phosphorus as limiting nutrient sources. Rampant growths of these organisms produce undesirable tastes and odors in potable waters, contaminate recreational areas, and limit populations of more desirable organisms such as fish. Significant reductions of all phosphorus species present in municipal wastewaters are technically feasible in existing treatment plants before effluents are discharged into receiving waters. These reductions are accomplished by modifying conventional primary or secondary treatment to include chemical precipitation and flocculation processes. The instrumentation and control systems for such chemical phosphorus removal processes are discussed in this paper.

CHEMICAL PRECIPITATION/FLOCCULATION

Chemical processes for removing dissolved and suspended phosphorus species from municipal wastewaters have been reviewed (10,13) and described in detail in the literature (1,2,6,8). These processes have been demonstrated to be effective in removing all forms of phosphorus at conventional wastewater treatment plants (11,14,16). Chemical precipitation and flocculation is usually applied in two process steps as shown in Figure 1. The first step consists of the addition of inorganic coagulants (2), such as ferric or ferrous iron, aluminum, or calcium salts (1,4,10,11,13,15,16) to the untreated wastewater. The metal ions of these coagulants combine with the dissolved phosphates present in the wastewater to form insoluble precipitates which remain in suspension. Ferrous and ferric chlorides have been the most effective

PHOSPHORUS REMOVAL BY CHEMICAL PRECIPITATION/FLOCCULATION

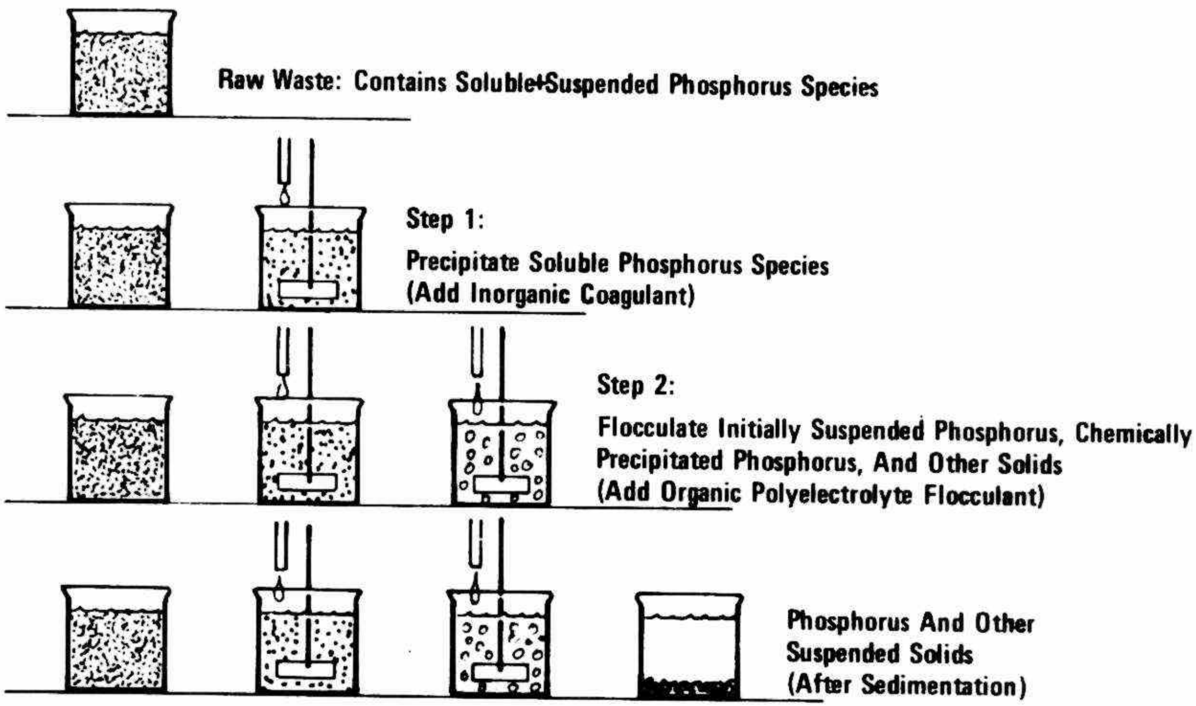


Figure 1

inorganic coagulants on a cost/performance basis.

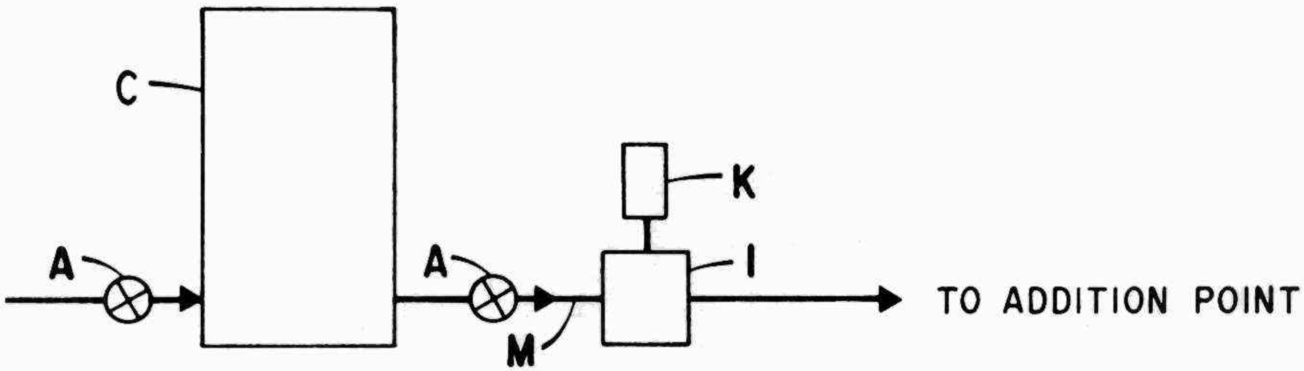
The metal-phosphate precipitates are small, colloidally stable, and usually cannot be separated entirely from wastewater by conventional sedimentation. The second step of the removal process, therefore, consists of the addition of small amounts of an anionic, water-soluble polyelectrolyte flocculant to effectively collect and agglomerate the small phosphate precipitates into large, readily settleable flocs. These flocs settle rapidly and effectively in conventional primary sedimentation tanks. Split addition of chemicals also has been applied for more extensive removal. This consists of chemical addition at two or more locations within a given plant such as before primary and before secondary clarification.

CHEMICAL FEEDING SYSTEMS

Chemical equipment for feeding chemicals to attain phosphorus removal is not complex and can be easily designed and installed. A typical inorganic coagulant feed system is shown in Figure 2. Inorganic coagulants are available as dry powders or granules, or as liquids containing 25-50% dissolved solids. Solutions of coagulants are not as viscous as flocculants and can be easily prepared and metered in the wastewater flow. Inorganic coagulants do require specific materials of construction designed to resist corrosion by acidic metal salt solutions. Aluminum and zinc-galvanized steel are not recommended. Exposed surfaces of storage tanks, pipes, and pumps should be made of glass fiber, rubber, or polyvinyl chloride.

A manually operated funnel disperser is used for preparing solutions of dry flocculant for treating relatively small volumes of wastewater. A flocculant feed system using an

INORGANIC COAGULANT FEED SYSTEM



A	VALVE	H	FEED TANK
B	WATER METER	I	PUMP
C	STORAGE TANK	J	TRANSMISSION
D	DISPERSER	K	MOTOR DRIVE
E	MIX TANK	L	DILUTION SYSTEM
F	FLOAT LEVEL CONTROL	M	PIPING
G	MIXER		

Figure 2

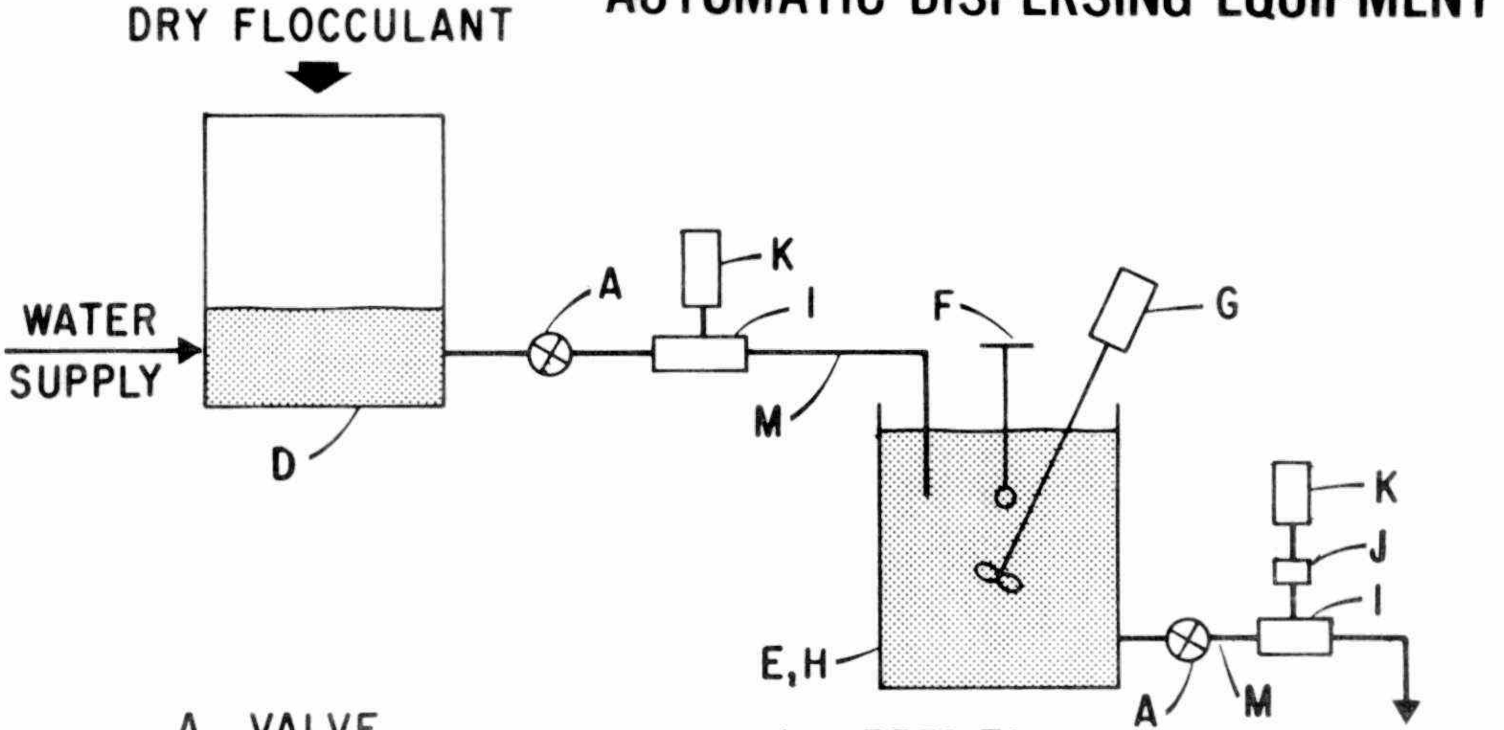
automatic disperser for treating larger volumes of wastewater is shown in Figure 3. An automatic flocculant disperser should be considered when treating water volumes in excess of 5 mgd.

The automatic flocculant disperser shown in Figure 4 is designed to prepare up to 200 gal/min of flocculant solution at a concentration of 0.25 percent by weight. Dry flocculant is added by a screw feeder at a variable rate ($\leq$10 lbs/min) into the vortex formed within a mixing bowl. Water at 40 psi and 25-100 gal/min is first passed through a strainer and a water meter before reaching a solenoid valve which is activated by a float control monitoring the liquid level in a feed tank receiving the prepared flocculant solution. The water flow is then split with most of the flow passing through a valve controlling the rear flow through the mixing bowl. The remaining water passes through a small internal reservoir also equipped with a float valve which maintains a desired level of water in the bottom of the mixing bowl for optimum dispersion of the dry flocculant.

The combined flow from the mixing bowl and the reservoir is then pumped through a pump at 25-100 gal/min directly to a larger feed tank or combined with another stream of dilution water (<100 gal/min) before delivery to the feed tank. The flocculant solution is mixed further in the feed tank before being displaced by the incoming flow and delivered to the point of addition in the treatment plant. The automatic flocculant disperser unit can be operated manually or mechanically.

Other more simplified units are commercially available for preparing flocculant solutions in the intermediate range of 0.5-25 gal/min. The manual funnel disperser is limited to the preparation of relatively small quantities of flocculant solution. An automatic bulk flocculant handling system should be

FLOCCULANT FEED SYSTEM UTILIZING AUTOMATIC DISPERSING EQUIPMENT



A VALVE
B WATER METER
C STORAGE TANK
D DISPERSER
E MIX TANK
F FLOAT LEVEL CONTROL
G MIXER
H FEED TANK
I PUMP
J TRANSMISSION
K MOTOR DRIVE
L DILUTION SYSTEM
M PIPING

Figure 3

AUTOMATIC FLOCCULANT DISPERSER

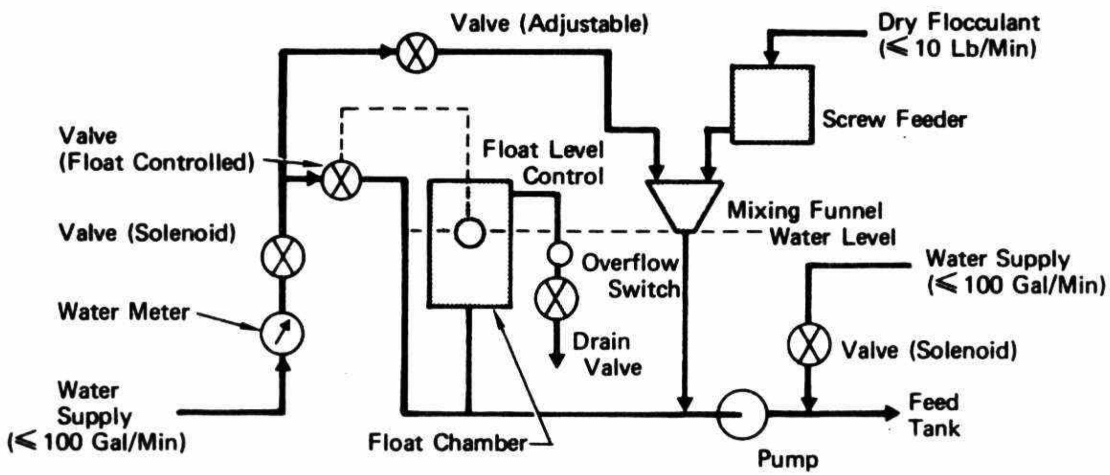


Figure 4

considered for treating very large volumes (100 x 10^6 gal/day).

Solutions of polyelectrolyte flocculants are highly viscous, and ordinary flow regulating valves and meters are usually not adequate to control the feeding of small volumes of solutions. Polyelectrolyte solutions exhibit non-Newtonian flow and special considerations should be made so that pumps and lines are not oversized on the basis of Newtonian flow properties (7). Solutions of flocculants are noncorrosive and standard materials of construction, such as polyvinyl chloride, black iron, and mild steel, can be used for all equipment.

SAFETY AND ENVIRONMENTAL ASPECTS

Most polyelectrolyte flocculants are relatively easy to handle. Slippery conditions can arise, however, if spills of flocculant solutions or dry powder occur. Minor spills should be flushed immediately with water. Major spills may require application of neutralizing or absorbing agents. Containment dikes are recommended to surround storage tanks containing inorganic coagulants.

Inorganic coagulants are only slightly irritating to intact skin if washed off promptly after contact. Organic flocculants are only slightly irritating to abraded skin but should also be washed off after contact to prevent accidents due to slippery conditions. Safe handling of inorganic coagulants generally requires operators to wear goggles and rubber gloves during transfer. Installation of eye and safety showers is recommended.

Inorganic coagulants and organic flocculants are generally applied under controlled conditions. They become associated with the sludges formed during water and wastewater treatment. Inorganic coagulants are not toxic to aquatic organisms unless

extreme pH changes are produced when excessive quantities are used. Organic flocculants have relatively low oral toxicities and have been declared suitable for potable water treatment by the U. S. Environmental Protection Agency.

Anionic and nonionic flocculants generally are not toxic to fish. Cationic flocculants can be toxic to fish if used incorrectly in low solids systems. They have been applied successfully in many applications following carefully controlled conditions. Detailed information on the proper and safe handling of coagulant/flocculant chemicals is available from the manufacturers.

INSTRUMENTATION AND CONTROL

In spite of the heterogeneous nature of most suspensions, continuous quantitative monitoring and control of the flocculation process has been realized in some applications (3,4,5,12). Some instrumentation has been applied to the control of coagulation processes (4,9,14). Instrumentation in both coagulation and flocculation processes has been limited to controlling the storage and preparation of chemicals, the metering of chemical additions, and the monitoring of influent and effluent qualities. Process analyzers have measured turbidity (5,9), surface charges (3,12), or ortho phosphorus concentration (4,14,17).

There is no universally applicable instrumentation or control system for coagulation/flocculation processes. Comparisons of typical flocculant preparation systems, flocculant addition systems, and coagulant addition systems for five ranges of total plant flow are summarized in Table I. The overall accuracy of the instrumentation is increased as warranted with increased plant size.

<u>Average Flow: <1 mgd</u> - The flocculant solution for small plants

TABLE I

INSTRUMENTATION AND CONTROL SYSTEMS FOR COAGULATION/FLOCCULATION PROCESSES

Average Plant Flow 1 Mgd = 10^6 gal/day	Flocculant Preparation System	Flocculant Addition System	Coagulant Addition System
<1	Manual operation; batch preparation in tank.	Manual operation; variable speed device with pump calibration and/or rotameter.	Similar to flocculant addition system.
1 - 10	Automatic operation; flocculant disperser; holding tank.	Automatic operation; variable ratio station; feed proportional to sewage flow.	Similar to flocculant addition system.
10 - 25	Same as above.	Same as immediately above with feedback correction and flow totalization.	Similar to flocculant addition system.
25 - 100	Same as above.	Same as immediately above plus tank level indicators and malfunction alarms.	Similar to flocculant addition system plus automatic influent analyzers/transmitters.
>100	Same as above; alternative bulk handling.	Same as immediately above.	Similar to flocculant addition system plus automatic analyzer/transmitter for both influent and effluent; density transmitter and use of empirical design equations.

(1 mgd = 10^6 gal/day) is manually prepared in a small storage tank. Addition rates are manually set by variable speed devices. Flow rate indication is provided by a pump calibration curve or a glass-tube rotameter. The coagulant solution is fed by manually-set variable-speed drives similar to the flocculant controls.

Average Flow: 1- 10 mgd - The flocculant solution is automatically prepared and automatically added to the influent flow by means of a variable-ratio station which varies the speed of the pump proportional to the influent flow rate. The addition system for the coagulant solution is similar to the addition system specified for the flocculant solution. Influent flow transmitter costs vary with the type of flow element that is employed at each plant. The preferable sensor is an electronic differential-pressure transmitter connected to a Venturi meter.

Average Flow: 10-25 mgd - The flocculant solution is automatically prepared as in the 1-10 mgd system and automatically added to the influent flow by means of a variable-ratio controller which varies the speed of the pump proportional to the influent flow rate. The actual amount of flocculant being added is sent to the controller as feedback. The controller determines the difference between what should be added and what is actually being added, and promotes the appropriate response by the pump motor. The coagulant addition system is similar to the flocculant addition system. Flow totalization of each stream can provide data for material balances.

Average Flow: 25-100 mgd - The flocculant solution is automatically prepared as described for the 10-25 mgd feed system. The flocculant solution is automatically added to the influent flow based on influent flow rates times a variable ratio as described for 10-25 mgd plants. Coagulant addition may be

automatically controlled on the bases of the influent concentration of a specific pollutant and/or flow rate. Automatic analyzer(s) and transmitter(s) may be required. A variable-ratio controller as previously described controls the coagulant addition rate. Continuous level transmitters on the coagulant storage tanks with high and/or low level switches to simplify loading and unloading operations should be included in this design. Flow recorders and flow totalizers provide data for material balances.

Average Flow: >100 mgd - Flocculant solutions to be used in plants of this size should be prepared using an automatic flocculant disperser and suitable holding tanks. A bulk handling system is an alternative to bag flocculant transfer. The flocculant solution is automatically proportioned to the raw waste flow based on influent flow rate times a variable ratio as in the previous descriptions. Coagulant feed is automatically proportioned to influent waste flow. It may be based also on empirical design equations for a specific waste stream if available.

A density transmitter on the coagulant feed determines the weight concentration of inorganic coagulant in solution which is multiplied by the coagulant flow rate resulting in a mass flow rate. Two analyzer/transmitters are employed. The calculated coagulant concentration is the set point of a variable ratio controller which receives as it measures the coagulant mass flow rate and operates a variable-speed pump to deliver the calculated amount of coagulant. Flow recorders and totalizers provide a material balance. Electronic/electrical instrumentation is preferable due to long transmission distances usually encountered in many treatment plants.

EXAMPLE CONTROL SYSTEMS

The U.S. Environmental Protection Agency has sponsored a demon-

stration project with the city of Grand Rapids, Michigan, where this technology currently is being used (3). Removal of total phosphorus at that plant is expected to meet the removal criterion required by the state of Michigan in 1973.

The automatic control loop for phosphorus removal at this location is shown in Figure 5. The coagulant is added first based on the product of a flow signal and a phosphorus concentration signal. The flocculant is added second based on a flow signal alone.

The coagulant feed system (4) is shown in more detail in Figure 6. The chemical used as the primary coagulant in this example was flocculation grade ferric chloride. Solution concentrations were varied seasonally depending upon anticipated storage temperatures. Tank truck deliveries were stored outdoors in two 12,000-gallon fiberglass-reinforced plastic tanks surrounded by dikes for safety purposes. Both tanks were provided with continuous level transmitters equipped with low-level alarms to facilitate feeding and loading operations. Unloading and/or transfer pumps, and acid-proof piping and valves were provided.

Ferric chloride solution was added to the influent wastewater by gravity flow in proportion to the total phosphorus load. This load is the product of the total phosphorus concentration in the influent sewage and the raw sewage flow rate. An automatic ortho-phosphorus analyzer (17) provided a signal linearly related to the ortho-phosphorus concentration. This signal was multiplied by the ratio of total phosphorus/ortho phosphorus concentrations. This modified signal was further multiplied by the influent sewage flow rate signal. The flow sensor was an electronic flow transmitter connected to an existing 72-inch Venturi tube. This allowed addition of the ferric chloride solution proportional to the total phosphorus

AUTOMATIC CONTROL LOOP
FOR PHOSPHORUS REMOVAL FROM WASTEWATER

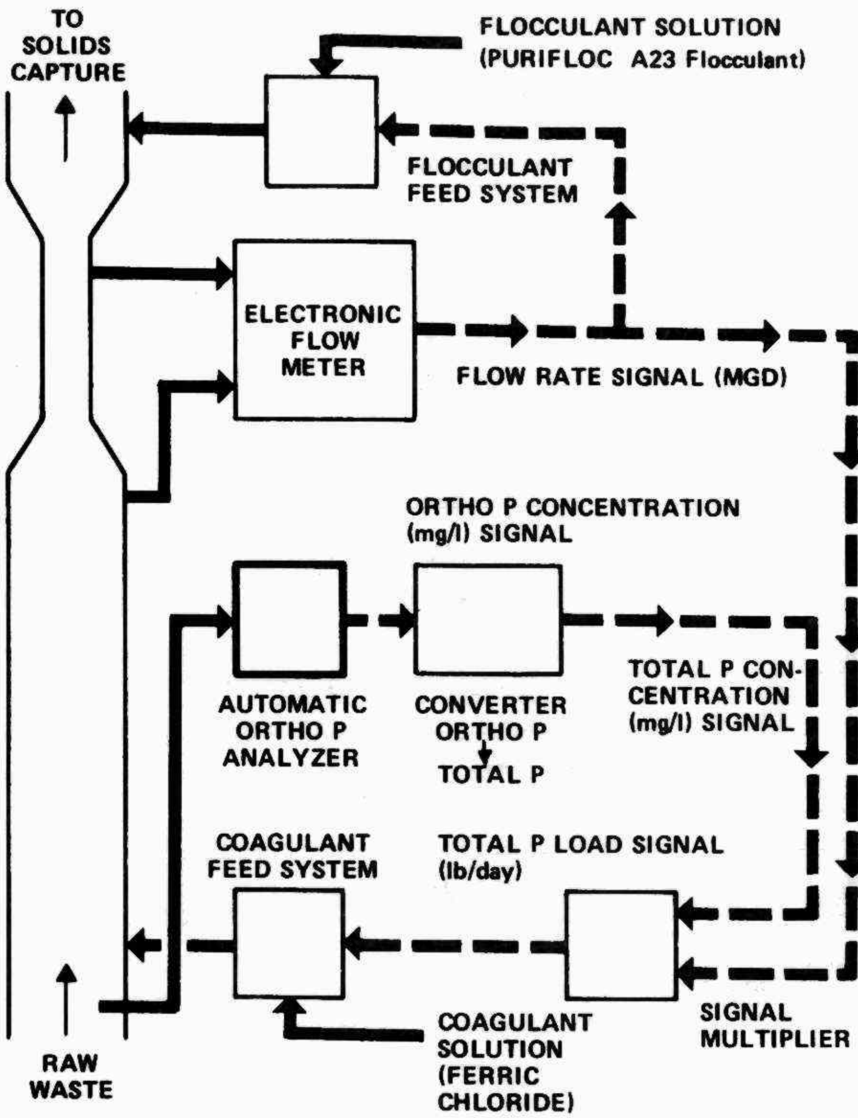
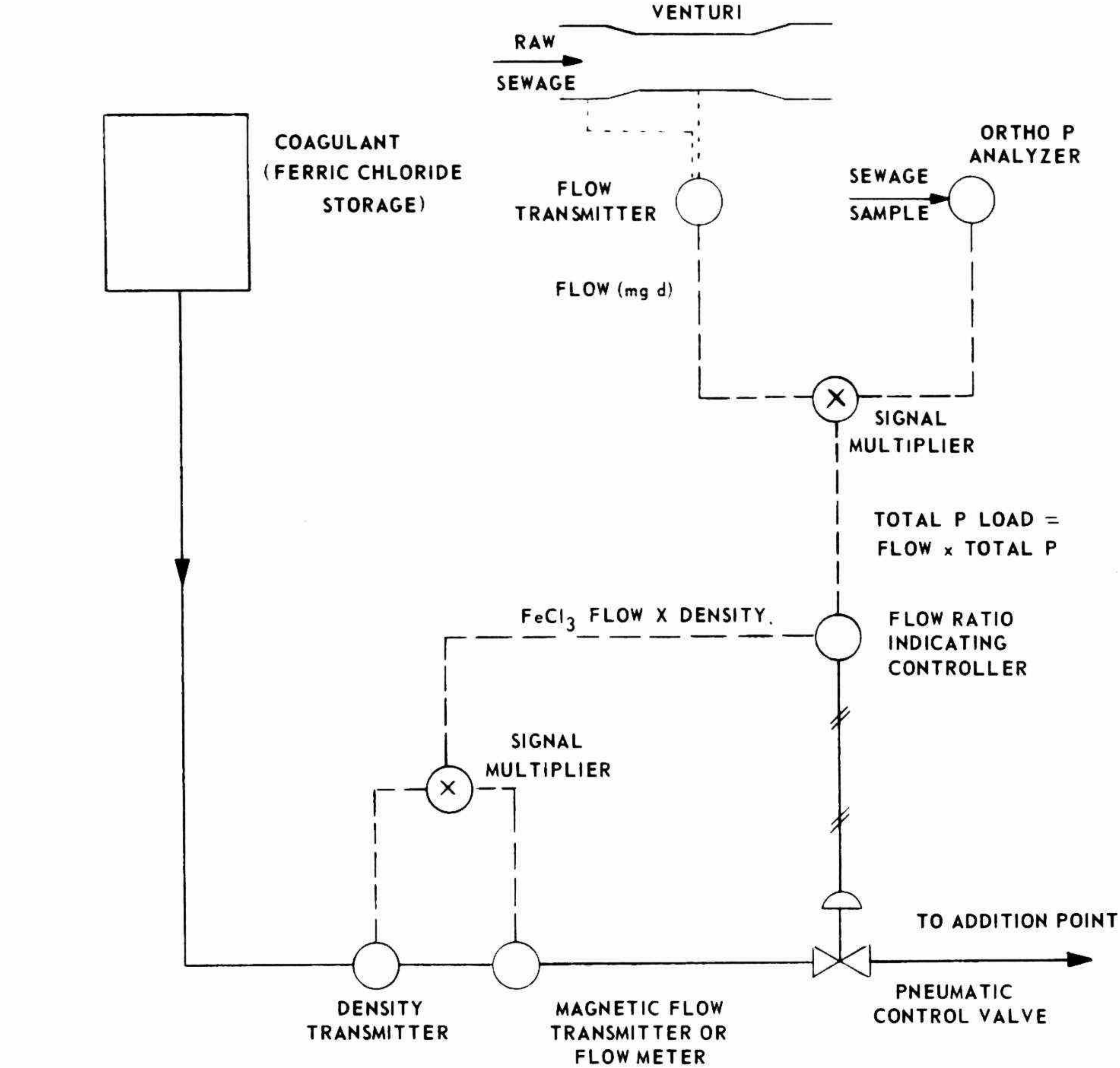


Figure 5



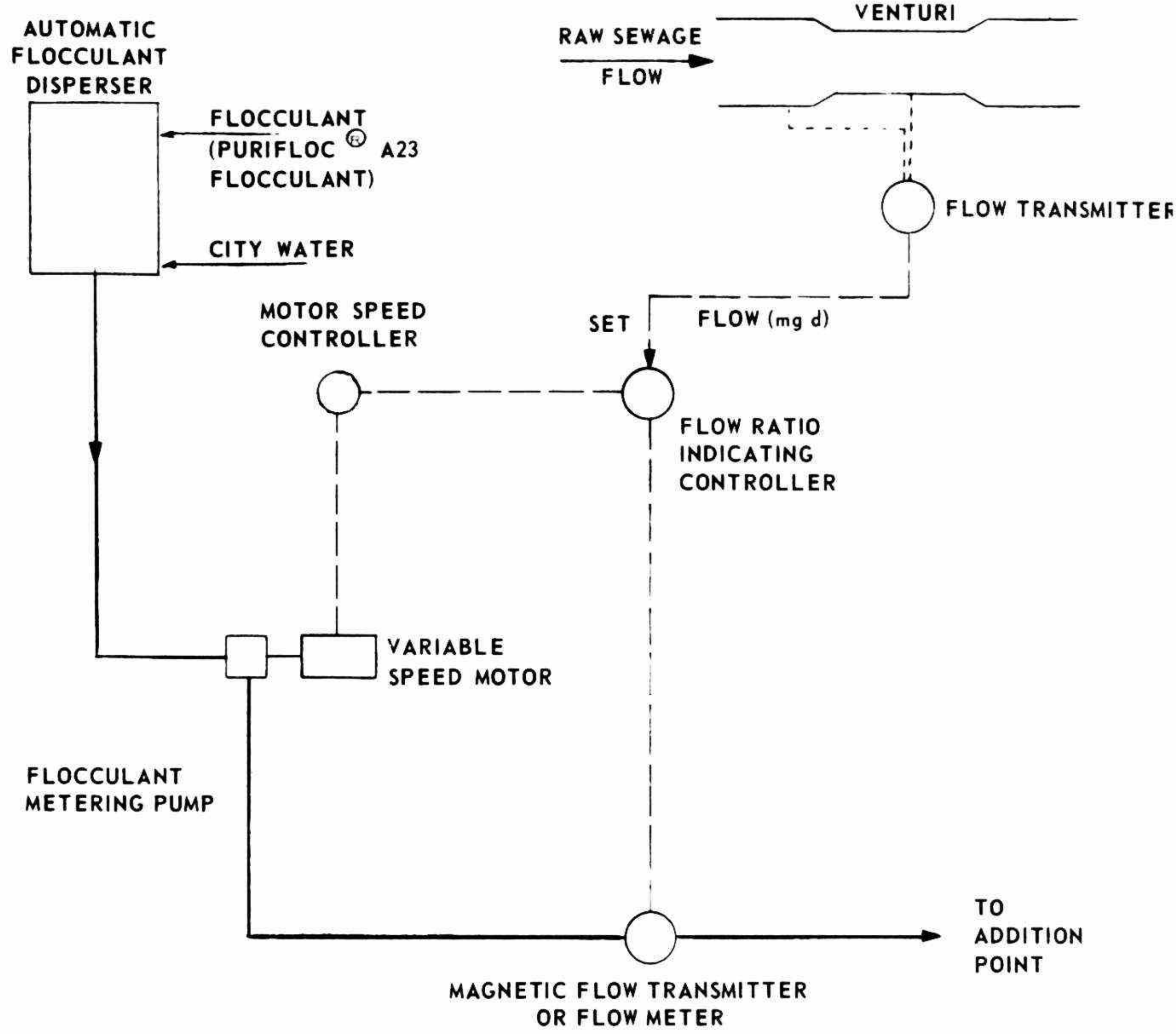
COAGULANT FEED SYSTEM

Figure 6

load (lb/day) to the plant.

A variable ratio controller was used to proportion the coagulant feed. The coagulant flow control devices were pneumatically operated control valves. A signal proportional to the actual amount of coagulant being fed as determined by a magnetic flow transmitter was returned to the flow ratio indicating controller as feedback. Differences between the required feed rate and the actual feed rate were determined by the controller which then initiated the appropriate response by two pneumatically operated control valves. A density transmitter consisting of a gamma source and detector continuously determined the weight contration of ferric iron in the coagulant feed solution. This determination multiplied by coagulant flow rate resulted in a signal to the ratio controller which actually fed ferric iron proportional to total phosphorus.

A schematic diagram of the flocculant feed system (4) is shown in more detail in Figure 7. The primary flocculant used in this example was an anionic organic polyelectrolyte, PURIFLOC A23 flocculant. Solutions were continuously prepared from bags of the dry flocculant using an automatic disperser. The resulting solution was then automatically added to the influent sewage by means of a flow ratio indicating controller. The solution feed pump drive was adjusted in proportion to the influent flow rate utilizing the same type of electronic flow transmitter previously described for the coagulant feed system. A signal proportional to the actual amount of flocculant being fed as determined by a second magnetic flow transmitter was fed back to the flow ratio indicating controller. The controller then determined the difference between the required feed rate and the actual feed rate and initiated the appropriate response by the pump drive. Speed indicators and low speed alarms were provided on the duplicate variable speed



FLOCCULANT FEED SYSTEM

Figure 7

D.C. drives. Flow totalizers and recorders provided material balance data on both the coagulant and flocculant feed systems.

PHOSPHORUS ANALYZER

A continuous ortho phosphorus analyzer (17) was installed to provide a permanent record of ortho phosphorus concentration at ten-minute intervals. An electronic signal was also generated for adjustment of the ferric chloride addition rate. This analyzer was originally developed by The Dow Chemical Company and has been licensed to Ionics, Inc. Ortho phosphorus is determined according to the standard colorimetric test using aminonaphthol sulfonic acid as the reductant ($SnCl_2$ is also compatible with the instrument). The sample is filtered to remove suspended solids prior to colorimetric analysis. An acid wash cycle is provided to prevent microbial growth on the internal surfaces of the instrument.

APPLICATION OF PHOSPHORUS REMOVAL PROCESSES

Chemical precipitation-flocculation processes are applicable to primary plants, and to both the trickling filter types and activated sludge types of secondary plants. The addition of chemicals can be made at any of several locations within a given treatment plant depending upon the available hydraulics and the desired extent of treatment. Improved removals of biochemical oxygen demand (BOD) and suspended solids are obtained in addition to phosphorus removal.

This technology has been applied on a laboratory scale at wastewater treatment plants in the Great Lake area which account for more than one-half of all of the municipal sewage flow into the Great Lakes. This process has been evaluated in actual full-scale operation at more than 20 different wastewater treatment plants. Many plants are currently in

design or construction or have already become operational to meet effluent criteria established by the various Great Lakes states.

Instrumentation is available to control the storage and preparation of chemicals used in the phosphorus removal processes. The addition of coagulants and flocculants can be metered automatically. Process analyzers also are available to monitor influent and effluent qualities.

REFERENCES

1. Barth, E. F., Brenner, R. C., and Lewis, R. F., Chemical-Biological Control of Nitrogen and Phosphorus in Wastewater Effluent, J. Water Pollution Control Fed. 40, 2040-54 (1968).

2. Campbell, T. L., and Daniels, S. L., Phosphorus Removal by Chemical Precipitation and Flocculation During Primary Treatment, prepared as part of the "Process Manual for Phosphorus Removal," U. S. Environmental Protection Agency Technology Transfer Program, No. 17010 GNP, October 1971.

3. Cardwell, P. H., Technique of Streaming Current Detection and Applications, Env. Sci. Tech. 1, 482-7 (1967).

4. City of Grand Rapids, Michigan, The Use of Iron Salts and Organic Polyelectrolytes for Removal of Phosphorus From Municipal Sewage, Program No. 11010 ENR, U. S. Environmental Protection Agency, report in preparation, 1973.

5. Daniels, S. L., The Utility of Optical Parameters in Evaluation of Processes of Flocculation and Sedimentation, Chem. Eng. Prog. Sym. Series 65(97), 171-6 (1969).

6. Daniels, S. L., Removal of Phosphorus and Nitrogenous Species from Wastewater, presented at the 45th Annual Meeting of the New York Water Pollution Control Association, New York City, New York, Jan. 23, 1973.

7. Daniels, S. L., A Survey of Flocculating Agents - Process Descriptions and Design Considerations, presented at the 74th Meeting of the American Institute of Chemical Engineers, New Orleans, La., March 13, 1973; to be published in "Water 1973."

8. Galloway, D. R., Phosphorus Removal by Chemical Precipitation and Flocculation, presented at the Lake Michigan Enforcement Conference, Reconvened Session, Chicago, Ill., September 19, 1972.

9. Hannah, S. A., Cohen, J. M., and Robeck, G. G., Control Techniques for Coagulation-Filtration, J. American Water Works Assoc. 59, 1149-63 (1967).

10. Jenkins, D., Ferguson, J. F., and Menar, A. B., Chemical Processes for Phosphate Removal, Water Research 5, 369-89 (1971).

11. Johnson, E. L., Beeghly, J. W., and Wukasch, R. F., Phosphorus Removal with Iron and Polyelectrolytes, Public Works 100(11), 66-8, 142 (1969).

12. Katzer, M. J., and Pollack, J. W., Clarifying Muddy Waters is Possible with Automatic System, Env. Sci. Tech. 2, 341-52 (1968).

13. Marson, H., The Removal of Phosphate from Sewage, Part I., Removal During Normal Sewage Treatment, Effluent Water Treatment Journal 11, 309-11, 313, 315 (1971).

14. Schuessler, R. G., Phosphorus Removal - A Controllable Process, Chem. Eng. Prog. Sym. Series 67(107), 536-40 (1970).

15. Singer, P. C., Anaerobic Control of Phosphate by Ferrous Iron, J. Water Pollution Control Fed. 44, 663-9 (1972).

16. Wukasch, R. F., New Phosphate Removal Process, Water and Wastes Engineering 5(9), 58-60 (1968).

17. Ionics, Inc., Automatic Phosphate Analyzer, Model 1836, Specifications, 65 Grove St., Watertown, Mass. 02172, 1972.

CHEMICAL HANDLING

THE CHEMICAL FEEDER AND ITS RELATED SYSTEM WHEN APPLIED TO ALUM, FERRIC CHLORIDE, LIME AND POLYMERS

Presented at the

Phosphorous Removal Design Seminar
Canada-Ontario Agreement
on
Great Lakes Water Quality

Toronto, Ontario
May 28-29, 1973

Mr. Terry Fahlenbock, P.Eng.
Control and Metering Limited
711 Kipling Avenue
Toronto, Ontario
M8Z 5G4

TABLE OF CONTENTS.

Page 2 ....

(1) INTRODUCTION.

This paper deals with handling four of the major chemicals used for phosphorous removal at a sewage treatment plant - namely - liquid alum, ferric chloride solution, lime and polymers.

Since various chemical suppliers have excellent catalogues covering the chemical characteristics, handling considerations and compatible materials of construction for these chemicals, points covered in these references will not be presented in this paper, however, a listing of the most popular suppliers of these catalogues is included in Sections 4, 5 and 8. It is recommended that these catalogues be obtained as a reference for designing a chemical handling and feeding system for phosphorous removal.

Since there seems to be some confusion these days regarding the automatic preparation of polyelectrolyte solutions from dry polymers, some design considerations of such systems are presented in this paper (see Section 7).

The major portion of this paper is devoted to the "heart" of the phosphorous removal system - the chemical feeder. Since the majority of chemicals are metered into the system as a liquid, the chemical feeder for liquids is the so called "metering pump". This amazing device, when selected and applied correctly often performs so well that it goes unnoticed in the system.

However, its selection is critical for application to a phosphorous removal system. It is for this reason that this paper will present in detail the various points to consider in the selection of the metering pump and its related components.

(2) METERING PUMPS.

(2.A) The Metering Pump as a 'Chemical Feeder'.

A chemical feeder is a device which accurately measures and controls the flow of chemicals (dry or liquid) at rates either automatically or manually controlled.

To illustrate"what a metering pump does" in fitting the above definition, another type of feed control system is shown below:

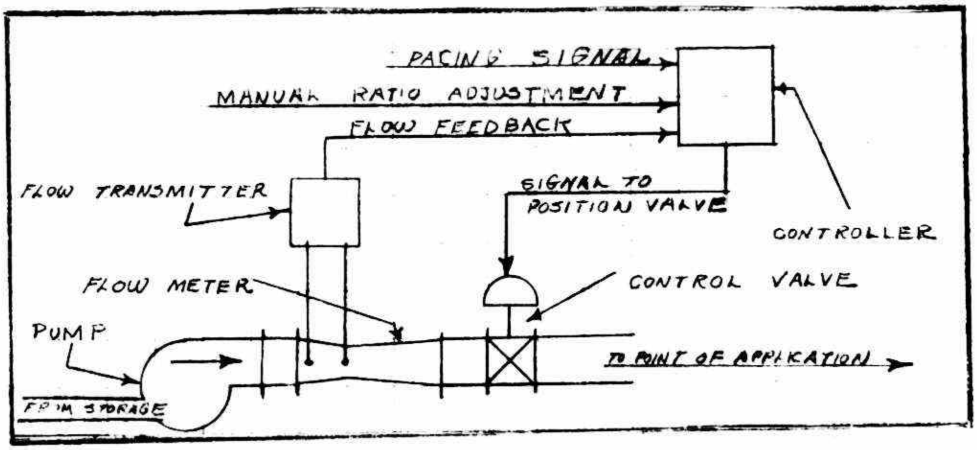


Fig. 2.1 - Schematic of Metering Pump Equivalent Performance.

A metering pump performs the same functions - only better. Its accuracy is better, its metering range is substantially greater, its control is more versatile, fewer components are required (as we will see), maintenance is less, calibration is far more simple and its capital cost is much lower.

As illustrated by the above schematic, a metering pump must not only be capable of pumping repetitively accurate volumes of chemical, it must have control capabilities which take into consideration:

(1) automatic pacing

(2) variable dosage adjustment capability

(3) overall metering range.

It is for these three reasons that the proper sizing and control method for a metering pump be carefully selected. A metering pump is principally a flow meter with integral flow controller; the 'pumping' capability is an added bonus!

(2.B) Stages of Design Development.

Metering pumps were first developed principally to meter small quantities of liquid chemicals (amine, hydrazine, phosphate, etc.) into high pressure lines of a boiler. Feed rate quantities were typically less than 1 gpm so that pumping rates were and still are traditionally expressed in "gallons per hour" (gph). Pressures varied between 300 psig. and 4,000 psig. with the majority of applications in the 600 psig. range.

This original metering pump incorporated a "packed plunger" drive mechanism, ball type check valves and a stroke length adjustment device capable of varying the pumping capacity from 0% to 100% of maximum rated capacity. The principle of operation and description of components is discussed later.

The "metering pump" thus developed had limited application in the water and sewage field until sodium hypochlorite solution became a popular method of purifying drinking water. The "packed plunger" design did not prove to be a good performer for this application. Since the packing allows leakage of this corrosive chemical, all exposed metal parts corroded badly with frequent replacement required. As a result, a zero leakage, "mechanically actuated diaphragm" metering pump was developed. Its metering head,check valves and diaphragm were of 'plastic' materials of construction. Even with its poor metering accuracy, this design proved to be ideal for this low feed rate application.

As time went on, the need for a metering pump capable of pumping larger quantities of corrosive chemicals was required. There seemed to be a limit of 25 gph for a "mechanically actuated diaphragm" pump since at high stroking rates (in excess of 100 spm), diaphragms larger than 4" in diameter and with a longer than ¼" stroke length experienced excessive failure rates. Also, the "mechanically actuated diaphragm" unit could not develop pressures in excess of 200 psig. at best.

To overcome the shortcomings of both the "packed plunger" and "mechanically actuated diaphragm" designs, the "hydraulically actuated diaphragm" metering pump was developed. It could pump at rates up to 400 gph per head and generate pressures up to 4000 psig. Diaphragm life was extended to better than 2 years.

Its performance was so excellent that it found applications outside the metering pump field. As a transfer pump for low pumping rates of corrosive chemicals these pumps had tremendous reliability and ease of maintenance. Other types,

(namely centrifugal, gear or progressing cacity) had shaft seals which proved troublesome. This application of the "traditional" metering pump did lead to some misunderstanding. Since the 'metering pump' is a positive displacement type, other positive displacement pump designs became confused with metering pumps, particularly when applications involved the metering of larger quantities of chemicals (up to 10 gpm). Gear pumps and progressing cavity pumps do have variable pumping rates corresponding to a varying rotor rpm, however, their application is utilized in transfering, not in metering, since their capacity control versatility is very limited and their pumping output characteristics are very pressure sensitive resulting in a suspect repetitive accuracy capability.

(2.C) Basic Design and Principle of Operation.

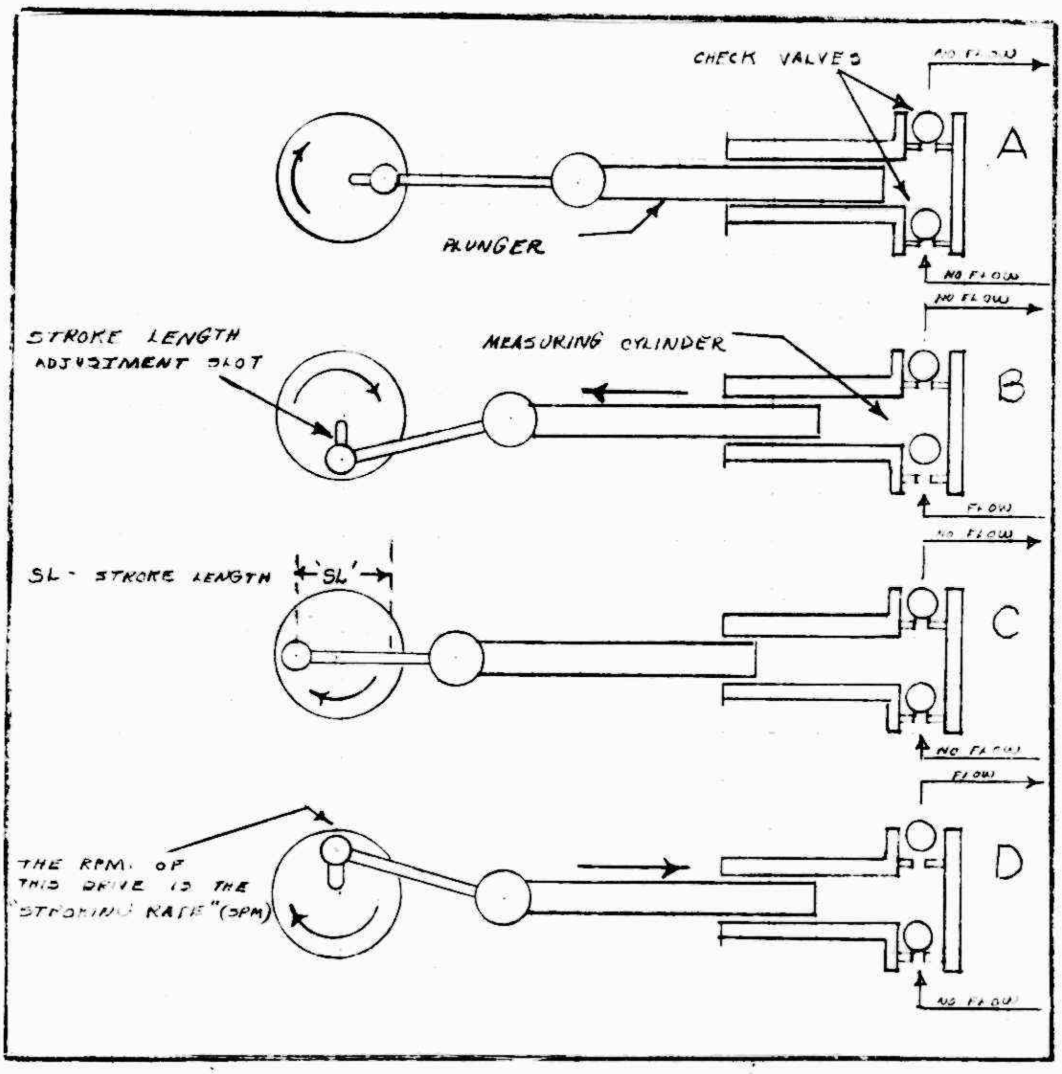


Fig. 2.2 - Metering Pump Basic Components and Principle of Operation.

In the above Figure 2.2, at 'A', the suction stroke is about to begin, the discharge stroke has just been completed and both check valves are closed. At 'B', one-half of the suction stroke has been completed, the suction check valve is closed; chemical is being drawn into the measuring cylinder out of the storage tank. At 'C' the suction stroke has been completed, the pump is ready to begin the discharge stroke. At 'D', one-half of the discharge stroke has been completed, the discharge check valve is open, the suction check valve is closed and chemical is being expelled out of the measuring cylinder to the point of application.

(2.D) METHODS OF CAPACITY ADJUSTMENT.

(i) Stroke Length Adjustment.

This method of capacity adjustment will be dealt with first since the standard metering pump design incorporates an integral stroke length adjustment mechanism.

Different manufacturers have different designs for this item, however, they are basically similar in that the "effective" length of travel of the plunger is variable from a maximum down to zero. At zero, the plunger (or diaphragm) doesn't move at all even though the drive mechanism is operating. The pump is in effect "spinning its wheels" and not doing any pumping.

There is a critical stroke length (normally at about 10% of full stroke length - some pumps 4%) below which the pumping output ceases to vary linearly with a decrease in stroke length. This is the 'range of accuracy' of the stroke length adjustment mechanism and is discussed further in 2.F.

(ii) Stroking Rate Adjustment.

This method of capacity adjustment is normally provided through some means of varying the speed of the drive motor. Most metering pumps are supplied with a constant speed, 1800 rpm. drive motor. A fixed stroking rate is provided through a speed reducer. As a result, for an individual pump selected, it has a fixed stroking rate unless variable position V-belt drive is provided or the speed reducer is changed.

Stroking rates in excess of 200 strokes per minute (spm) or lower than 10 to 20 spm. are not recommended. Most hydraulically actuated diaphragm

pumps are capable of the 200 spm. limit without noticeable deterioration of the diaphragm life. At too low a stroking rate, it appears that the check valves have a random 'leak' characteristic with a resulting very random pumping output.

This lowstroking rate limitation must be watched carefully when using a variable speed drive motor. For example, if the metering pump selected has a stroking rate of 60 spm. at the maximum drive motor rpm., at 1/10th drive motor rpm., the stroking rate would be 6 spm. - well below the acceptable limit.

(2.E) Pumping Characteristics.

(i) Output Flow

Refer to Fig. 2.2 and Fig. 2.3 below -

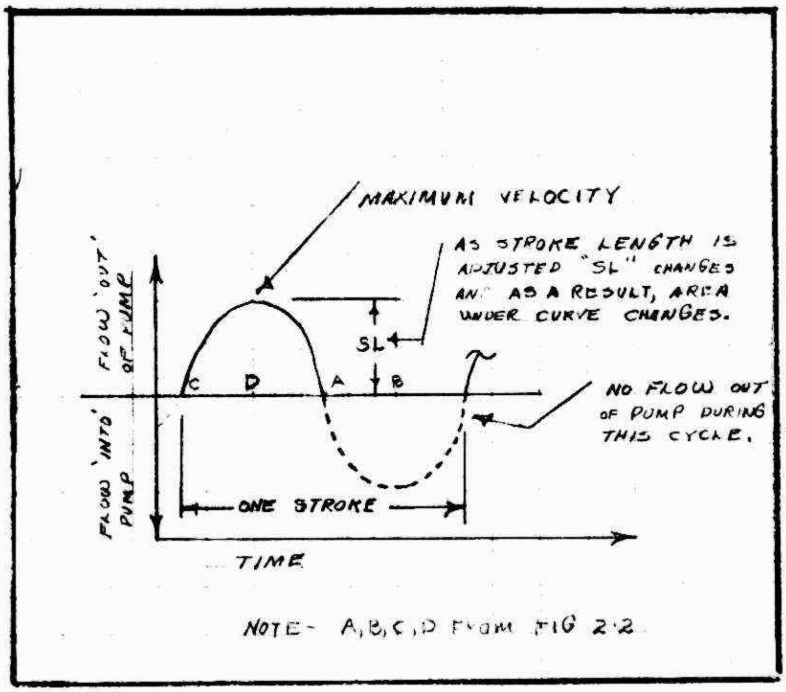


Fig. 2.3 - Metering Pump - Output Flow Characteristics.

This pulsating flow characteristic does cause some difficulty in certain cases. Generally its effects are most severely felt on high pressure systems. Suction and discharge line sizing play a major role in minimizing any "hammer" associated with these pulsations. As suggested in Section (2.H) a simple stand pipe accumulator can greatly reduce this characteristic.

(ii) Discharge Pressure:

A metering pump is capable of pumping against a pressure. This capability is dependent on the motor horsepower, the speed reducer rating, the stroking rate, the stroke length and the plunger diameter. In selecting a metering pump, the only important consideration is whether or not the pump can generate a pressure slightly in excess of the system pressure into which the chemical is to be discharged. The metering pump only generates as much pressure as it has to, to overcome the pressure imposed on it. Therefore, if the pump is discharging to atmosphere it only generates sufficient pressure to overcome the head of chemical in the discharge piping plus the pressure losses in the piping. However, it is important to realize that these pumps can generate high pressures. If a valve is closed in the discharge line, or if the line is blocked, frozen, etc., the pump will generate sufficient pressure to either break the discharge line, damage the cylinder or check valves on the pump, or burn out (cut-out) the drive motor.

As discussed in (2.H) a relief valve (preferably on the hydraulic fluid) is highly recommended.

(iii) Suction Head and Suction Lift:

Metering pump output is completely independent of the suction head conditions since during the discharge cycle of the stroke, the suction valve is closed.

If the suction head is greater than the system discharge pressure then undesirable syphoning will occur through the pump. This is eliminated by using an anti-syphon valve (back pressure valve) as discussed in Section 2.H. Once again the importance of "sufficient back pressure" is exemplified.

Most hydraulically actuated diaphragm pumps have a suction lift capability. For liquids with viscosities in excess of 1000 cps. it is recommended that the pump be positioned such that it has a suction head at all times.

(iv) Effects of a Varying Discharge Pressure:

A metering pump's output should not vary with a varying system pressure into which the pump is discharging. This characteristic is found to be correct provided that a minimum discharge pressure is provided. This 'critical' minimum back pressure is discussed in Section (2.H) where sizing for a back pressure valve is outlined.

Figure 2.4 below illustrates the above characteristics.

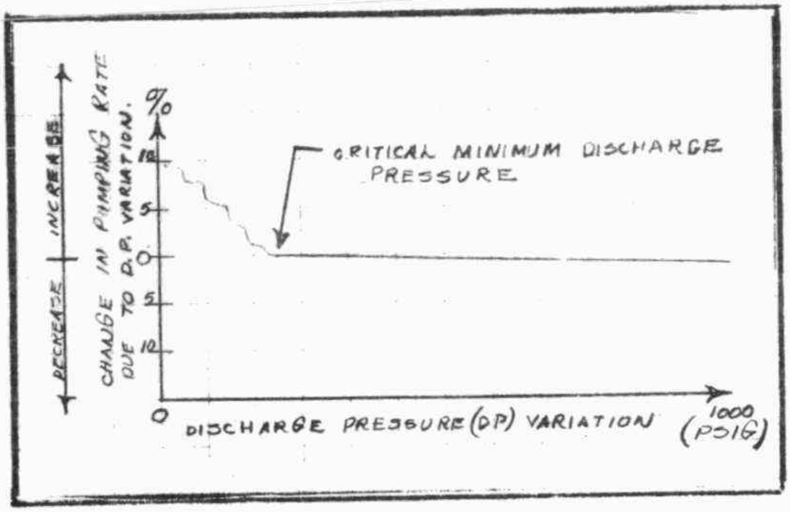


Figure 2.4 - Effect of a Varying System Pressure on the discharge characteristic of a metering pump.

(v) Output Versus Stroke Length Variation.

Above a certain minimum stroke length, the output of a metering pump varies linearly with a variation in stroke length. This is shown in Fig. 2.5 below.

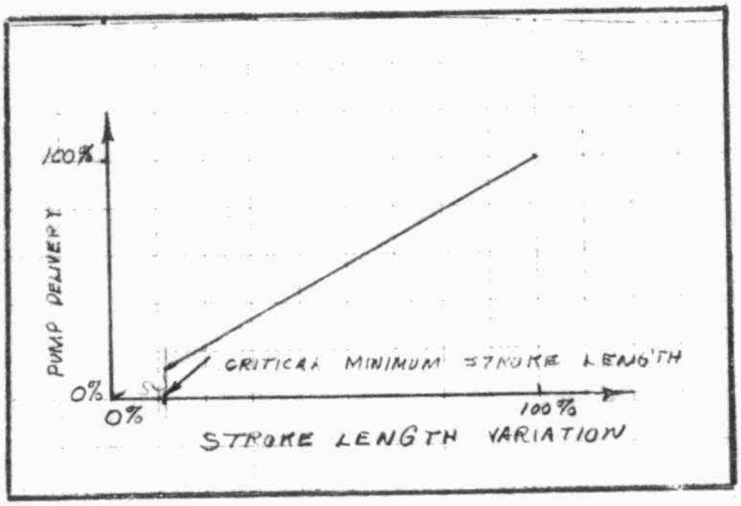


Fig. 2.5 - Metering Pump Output Versus Stroke Length Variation.

(vi) Output Versus Stroking Rate Variation.

Generally between 20 spm and 200 spm., the output of a metering pump varies linearly with a variation of the stroking rate. This is illustrated by Fig. 2.6 below -

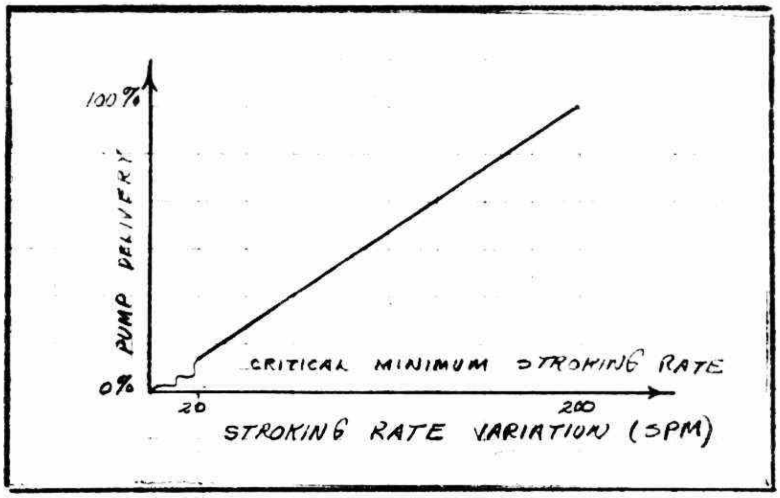


Fig. 2.6 - Metering Pump Output Versus Stroking Rate Variation.

(vii) Repetitive Metering Accuracy.

If several consecutive samples of (say) 20 minute duration of the discharge of a metering pump were taken, it would be found that the volumes collected would not vary from one another by more than (say)±1%, provided of course, that the stroke length and stroking rate were held constant. If this same procedure were performed at several stroke lengths and stroking rates within the accuracy range stipulated for the pump, it would be found that the corresponding collected volumes would also not differ from one another by more than the stated accuracy (say ± 1%) of the particular metering pump.

This is what an accuracy statement for a metering pump means. It is discussed in further detail in Section (2.F) with the implications of automatic pacing discussed in Section (2.G).

Because of the 'wearing' characteristics of the check

valves of a metering pump, this metering accuracy characteristic does not vary gradually with pumping time. The output accuracy remains valid, until the check valves are completely worn out and will no longer 'seat' properly.

(viii) Why such a big motor for such a small pumping rate?

Motor horsepower is calculated from the force acting on the diameter of the plunger (i.e.- the system discharge pressure in psig), the (cross section) area of the piston, the stroke length and the stroking rate plus losses in the speed reducer (etc.) plus the suction stroke loss.

From these parameters, the following simple formula will give the approximate horsepower requirements:

$$Hp = \pi \times R^2 \times P \times \frac{SL}{12} \times \frac{SR}{60} \times \frac{1}{550} + \text{losses.}$$

R = plunger radius (ins).
P = discharge pressure (psig.).
SL = stroke length in inches.
SR = stroking rate (spm.)

E.G - Plunger Radius - 1"
Discharge Pressure - 200 psig.,
Stroke Length - 3"
Stroking Rate - 200 spm.,
Losses - 0.05 hp.

Therefore - Hp - (approx.) =

$$3.14 \times 1^2 \times 200 \times \frac{3}{12} \times \frac{200}{60} \times \frac{1}{550} + 0.05 = 1 \text{ H.p. (approx.).}$$

(2.F) ACCURACY:

(i) What do Accuracy Statements Mean?

At this point it is well worthwhile to point out some pitfalls of accuracy statements. The most meaningful statement is "accuracy is $\pm$ x % of actual rate". In this case, if a pump is said to deliver $\pm$ 1% of actual rate, at 100 gph. it is accurate to within $\pm$ 1 gph., at 10 gph, it is accurate to within $\pm$ 0.1 gph.

A statement "$\pm$ x % of maximum rate" is misleading. Granted, at 100 gph. the pumping rate is accurate to within $\pm$ 1 gph however, at 10 gph, it is also accurate to within $\pm$1 gph. At this rate it is in effect only accurate to within $\pm$ 10% of the actual pumping rate.

(ii) A Metering Pump Accuracy Statement.

A metering pump's accuracy is based on its ability to pump repetitively accurate volumes of liquid when the stroke length and stroking rate are held constant (refer to Section 2E).

This statement holds true over a stroking rate range of say 20 spm to 200 spm (or whatever is the maximum spm) and over a stroke length range - normally 10 to 1. Better pumps have a 25 to 1 stroke length adjustment range.

Notice, that if the metering pump has a maximum stroking rate of 200 spm and a 25 to 1 stroke length range, then the metering pump could accurately deliver repetitive volumes over a 250 to 1 range from its maximum pumping rate capability.

Most metering pumps claim a repetitive accuracy of $\pm$ 1% of actual pumping rate over some stroke length range and over some stroking rate range if the stroking rate is to be varied.

(iii) Range of Accuracy.

An accuracy statement is not complete unless it states a range over which this accuracy applies. Beyond the accuracy range of a device, (this includes flow meters, etc.) you cannot expect a result better than between 0 and the rate at the bottom of the accuracy range. For example: If a metering pump is rated at 100 gph and has an accuracy statement $\pm$ 1% of maximum over a 10 to 1 range, at the 10 gph setting it could be delivering 11 gph or 9 gph. At any setting below 10 gph the pumping rate could vary randomly between 0 gph and 10 gph. Operation of equipment beyond its accuracy range is not in any way shape or form worthwhile.

(2.G) Sizing the Metering Pump and Selecting the Method of Capacity Adjustment.

(i) For Strictly 'Manual' Control.

Refer to Section 3 for determining the maximum chemical feed rate, the minimum chemical feed rate and the 'range of accuracy'.

Select a metering pump that has a maximum capacity slightly above the maximum requirements of the system. Determine the minimum accurate delivery capability of the pump by dividing the maximum pumping capability by the stated range of accuracy for the pump. If this feed rate is lower than required by the system then the pump is suitable. If this feed rate is higher, consider another manufacturer or consider some type of manual variable speed drive.

(ii) For Automatic Pacing.

(a) Make sure there is enough control range.

Normally for automatic pacing the 'range of accuracy' required by the system is greater than the 'range of accuracy' obtainable by varying only one of either the stroke length or the stroking rate. As a result, normally the stroke length is left as the manual dosage control and the stroking rate is varied from the pacing signal. Refer to Section 3 for determination of the metering pump sizing.

(b) The most common pacing signals and how to utilize them.

1. Time Impulse - this type of control offers the most accurate, least expensive and most easily maintained method of control. The flow signal is a contact closure for a fixed period of time out of a total time cycle. Eg. - for a fifteen second total cycle, if full flow is represented by a 13 second contact closure and a 2 second contact opening; during successive 15 second intervals, half flow would then be represented by a 6½ second contact closure and an 8½ second contact opening. This control signal can be transmitted over any distance.

To accept this signal, the metering pump is supplied with an electromagnetic clutch between the constant speed AC drive motor and the metering pump speed reducer. The stroke length adjustment mechanism would be used for manual dosage setting.

2. Electronic - (4-20 ma DC and 10-50 ma DC are the most common). It is recommended that the meter-pump be supplied with an SCR variable speed drive (with tachometer generator feed back) capable of accepting the above signal. It is also recommended that the SCR controller be supplied with a speed indicator from the tach-generator and an incoming signal milli-ammeter. These two values can then be compared to ensure proper speed response from the drive motor to the pacing signal. The stroke length adjustment mechanism is used for manual dosage setting. Be careful that the minimum stroking rate at the lowest flow signal does not produce a stroking rate lower than 20 spm.

3. Pneumatic - 3-15 Psig. It is recommended that the metering pump be supplied with a stroke length adjustment mechanism capable of accepting this signal. If the overall required metering range is greater than the stroke length adjustment range of accuracy, then a manual variable speed drive would also be required to manually vary the stroking rate for dosage setting.

NOTE: - It is important to know the actual flow signal at the maximum design flow to be treated. Eg. The maximum flow to be treated might be 1 Migd, while the flow meter is rated for 2 Migd and gives half signal at 1 Migd. Careful attention would have to be paid to this situation and either the pump would have to be sized larger or the flow signal "expanded" to a higher value.

(c) Control from two separate pacing signals.

If the metering pump is to be paced from two variables (e.g. - a flow signal and a pH or phosphorous signal) then it is recommended that the flow signal be either time-impulse or electronic and adjust the stroking rate while the other signal be electronic or pneumatic and adjust the stroke length. A metering pump is an ideal device for pacing from two variables due to its extremely versatile control. Fig. 2.7 shows one such system and also details the various components of the stroke length and stroking rate automatic positioners.

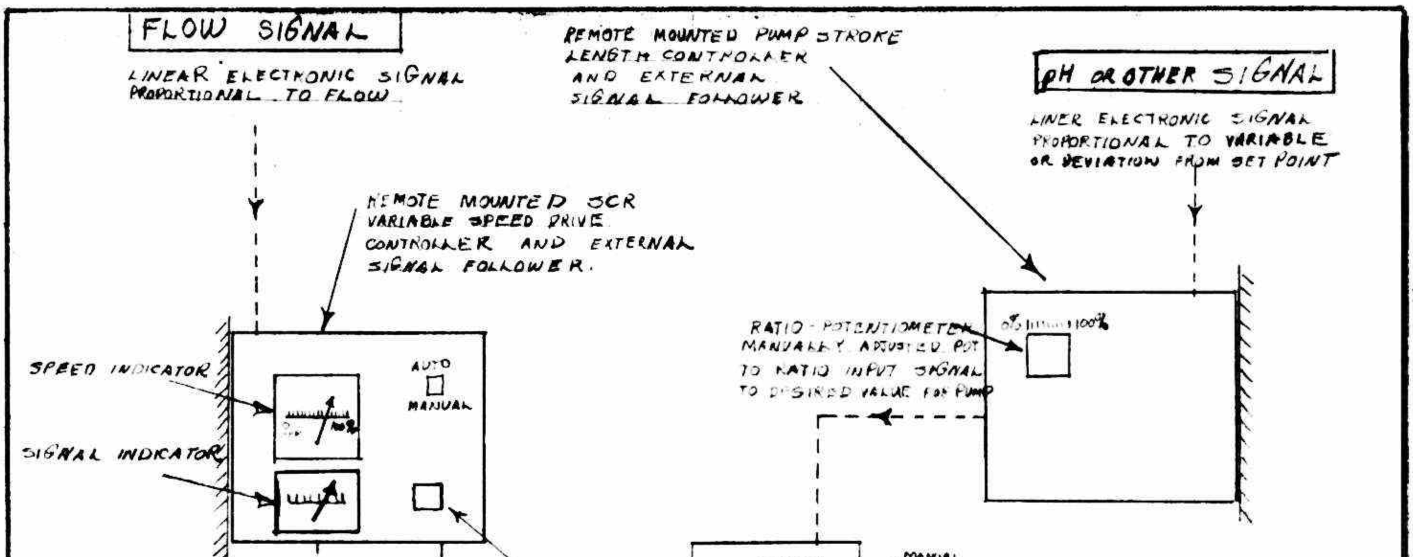


Fig. 2.7 Metering Pump - Automatic Control from two pacing signals.

(d) What happens to accuracy in a paced system.

As noted previously, the metering pump accuracy statement only covers the repetitive pumping accuracy of the pump and assumes that the stroking rate and stroke length are positioned without error.

With automatic control, some control device actually positions the stroking rate or stroke length to a value in accordance with an automatic pacing signal. Any error in this positioning adds to the inaccuracy of the pump. It is in this controller that most of the inaccuracy of a metering pump exists and these devices must be carefully selected.

The total system inaccuracy will include the inaccuracies of the pacing signal itself, the inaccuracy of the metering pump capacity adjustment 'positioner' plus the metering pump itself. Each plays an important part.

(2.H) Accessories and System Components.

(i) Check Valve Design.

Check valves are the major items on the pump which should be periodically inspected for wear or "blockage".

Check valves which can be removed without disturbing the suction and discharge piping are a definite advantage. This type of valve can be removed in seconds making inspection easy. Traditional types are threaded into the line and require a major disassembly procedure for inspection.

(ii) Relief Valve - should be internal hydraulic.

Since a metering pump is capable of generating pressures normally in excess of the discharge piping rating of the system, a relief valve is an important design requirement.

Relief valves on the process fluid have traditionally not been used for low discharge pressure systems on corrosive chemicals since no relief valves proved reliable for the service. With the introduction of the "hydraulically actuated diaphragm" pump, however, it was possible to put the relief valve on the hydraulic drive fluid and give protection to the system: These valves form an integral part of the pump and are fully piped and mounted on the pump. A relief valve should be required in a system to meet Department of Labour regulations.

(iii) Back Pressure Valve.

To ensure a linear discharge characteristic with varying stroke length and stroking rate, a metering pump requires a minimum "back pressure". This required minimum back pressure (BP)

is approximately calculated by the following formula:

$$\text{Required BP(psig)} = \frac{\text{Maximum rated capacity (Igph)}}{(\text{diameter (inches) of suction connection})^2}$$

Besides providing a linear pumping characteristic, a tight seating back pressure valve also eliminates any 'syphoning' through the pump should the suction head be greater than the discharge pressure as discussed in Section 2E (111). Back pressure valves that "fail-safe" are of a preferred design. Others let chemical "squirt" out.

It is to be noted that as yet no reliable "back pressure valve" has been developed for slurry service. (see V11 for a suggestion).

(iv) Suction and Discharge Piping.

The following formula should be taken into consideration when sizing suction and discharge lines:

$$I.D. = 0.14\sqrt{Q} \quad \text{(viscosity below 1000 cps) where I.D. = I.D. of suction and discharge line.(ins)}$$
$$Q = \text{max. metering pump capacity (USGPH).}$$

This formula assumes the max. desired line velocity at 2 ft./sec and takes into account a velocity correction factor for metering pumps at 2π. This velocity correction factor is necessary due to the "sinusoidal" flow characteristic. If an accumulator is used on the discharge line, its I.D. can be sized without using this factor. Suction lines should be kept short, particularly for slurries and viscous chemicals.

If the viscosity is above 1000 cps, the suction line diameter should be increased above that stipulated in the formula. The amount of increase is a function of pumping rate, viscosity, suction line length and head of suction on the pump. Note, for viscosities in excess of 1000 cps, the pump must have a flooded suction.

Note - when pumping lime slurry, suction and discharge lines should be flushed with water daily. Place a water supply line between the tank shut-off valve and the pump suction connection - See Fig. 2.8 (section vi) - the water supply line can replace the graduated cylinder.

(v) Where to put the shut-off valves?

The following valves are recommended in the system:

(a) At the storage tank - suction line connection.

(b) If the suction line is longer than say 10 feet, or if more than one pump is fed from the same header, then a valve should be placed close to the pump suction connection.

(c) Close to the pump discharge connection.

(d) Depending on the system, a valve may or may not be placed at the point of application.

(vi) Flow Indicator and Pump Calibrator

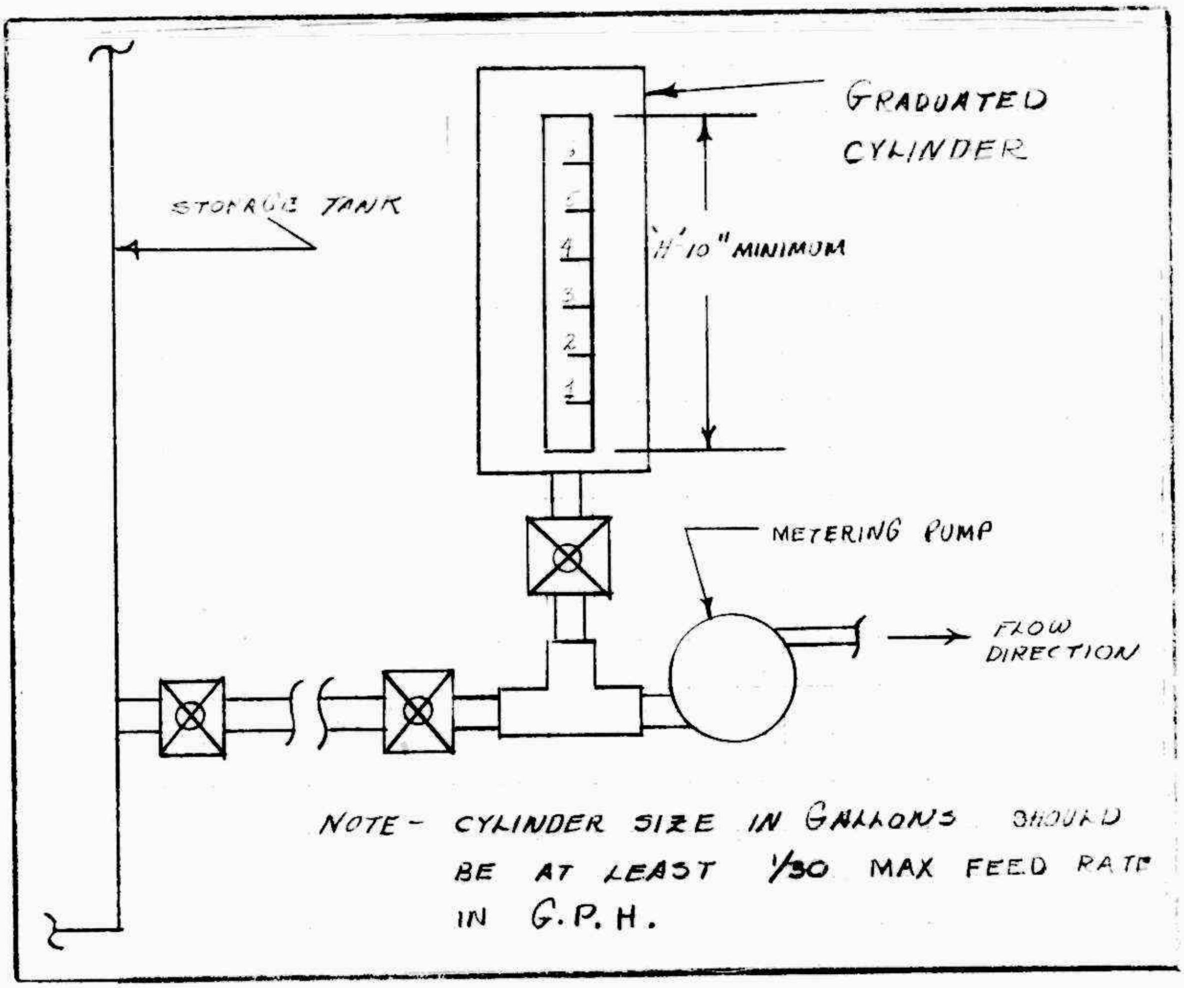


Fig. 2.8 - Metering Pump - Flow Indicator and Pump Calibrator.

It is difficult to determine when looking at a metering pump that is running whether or not it is pumping and whether or not it is pumping the proper amount. A device as shown in Fig. 2.8 will provide a simple, quick and accurate check of both requirements.

The graduated cylinder can be filled with process chemical or with another compatible liquid (e.g. - water).

To check for pumping rate,open the valve on the graduated cylinder and close the valve to the chemical storage tank. Time how long it takes for a calibrated volume to be pumped out. From this, calculate the equivalent gph and compare this to the desired value.

Size for the graduated cylinder is suggested to be such that at maximum pumping capacity, the graduated cylinder empties in no less than 2 minutes.

This device has another advantage. If it is filled with water (or a compatible flushing liquid for the chemical being utilized) the pump can be flushed out prior to inspection of check valves, etc., and thus avoid chemical spills on the floor.

(vii) A Simple Stand-Pipe Accumulator.

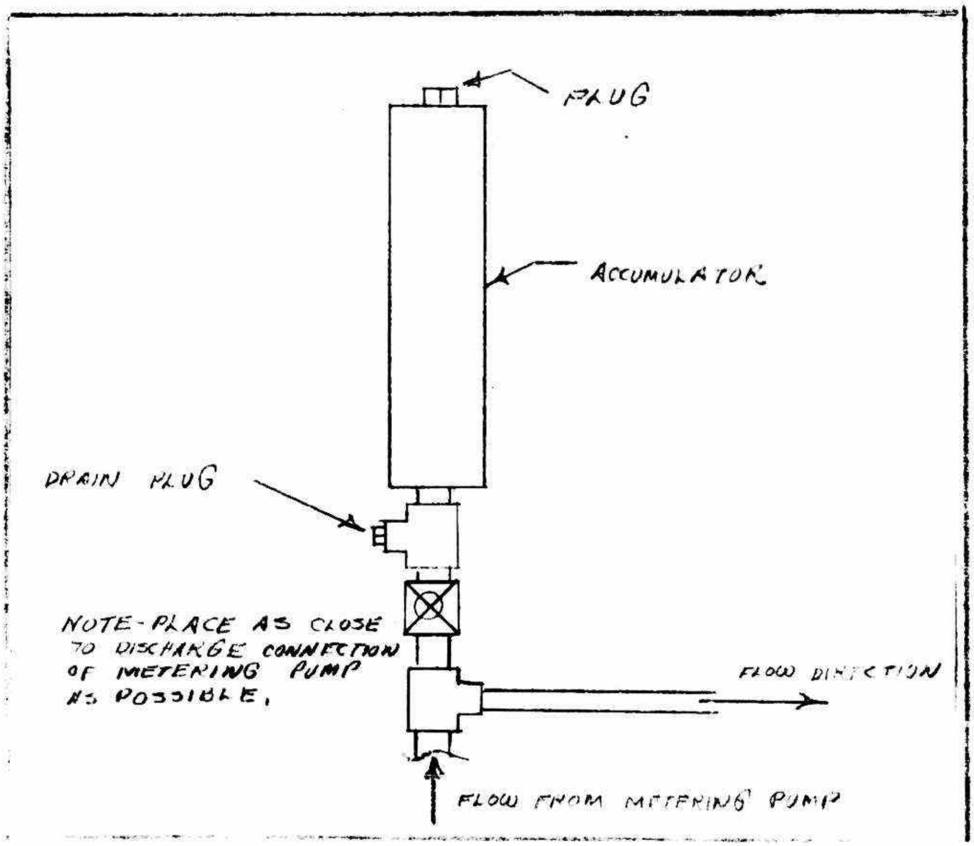


Fig. 2.9 - Stand-Pipe Accumulator For 'Damping' Pulsations Generated by a Metering Pump.

Should pulsations not be an acceptable characteristic in the chemical feed system; the stand-pipe accumulator shown in the above Fig. 2.9 is recommended as a simple corrective measure. In use, the air which is initially held under pressure in the stand-pipe dissolves in the chemical being pumped and as a result periodic draining of this accumulator is required.

Sizing of the Accumulator can be made utilizing the following formula:-

(a) For stroking rates less than 100 spm -

$$\text{Volume (gallons)} = \frac{5 \text{ X max. pumping rate (gpm).}}{\text{stroking rate (spm).}}$$

(b) For stroking rates above 100 spm -

$$\text{Volume (gallons)} = 5 \text{ X } \frac{\text{max. gpm}}{100} \text{ X } \frac{\text{spm.}}{100}$$

This accumulator should be placed as close to the discharge connection of the pump as possible.

This accumulator when coupled with a restricting orifice downstream of (but close to) the accumlator could be utilized as an effective back pressure device when pumping slurries.

Sizing and materials of construction of the orifice would be critical. With no field data on this suggestion at the present time, a sizing formula is not available.

(2.I) Recommended "Performance" Specifications.

It is recommended that the specifications for the metering pump contain as many details as possible about the entire system that have a bearing on the metering pump. The details of this system could be included under a heading "Metering Pump System Considerations" and follow a format such as:

The metering pump is to handle see (1) solution (slurry) in a see (2) % concentration. The temperature of this solution will not be above see (3) deg. F. nor below see (4) deg. F. This chemical will be contained in a nearby storage tank such that the suction line length will be not more than see (5) ft. and the suction head (lift) will approximately vary between see (6) ft. and see (7) ft. The discharge line length will be approximately see (8) ft. from the metering pump to the point of discharge and this point will be above (below) the elevation of the metering pump by see (9) ft. The chemical is discharged at the point of application (select one) -

(a) to atmospheric pressure.

(b) into a pipeline or vessel at see (10) psig.

The metering pump must be capable of delivering a maximum of see (11) gph of the above chemical.

This represents treating a maximum flow of see (12) gpm. at a dosage of see (13) mg/l. The minimum practical flow to be treated is see (14) gpm while the minimum probable dosage will be see (15) mg/l. This represents a range of see (16).

Select either (a), (b), or (c) below -

(a) The metering pump must be capable of having its capacity manually varied from the maximum capacity down to see (17) gph.

(b) The metering pump must be capable of having its capacity automatically varied over the entire above flow range from a see (18) pacing signal. The actual flow corresponding to the maximum pacing signal is see (19). Dosage is to be adjusted manually

over the entire dosage range of see (20)

(c) The metering pump must be capable of having its capacity automatically varied over the entire above flow range from a see (18) pacing signal. The actual flow corresponding to the maximum pacing signal is see (19). Dosage is to be adjusted automatically over the entire dosage range of see (21) from a see (22) pacing signal.

The metering pump motor must be suitable for see (23) electrical characteristics. The metering pump and motor must be coupled together and monted on a common floorstand.

Metering Pump Design - (recommended points to include)

The metering pump shall be a positive displacement hydraulic actuated diaphragm pump. The pump delivery shall be repeatable within ± 1% of actual output over the entire see (16) range.

Each head shall be suitable for metering and pumping the chemical solution (slurry) at the rates and under the conditions stipulated in the previous "Metering Pump System Considerations".

Select one of (a) or (b).

(a) The metering pump is to be supplied with a manually adjustable stroke length adjustment mechanism capable of varying the pumping rate from 0% to 100% of rated maximum capacity and provide positive repeatable settings within ± 1% over the range stipulated above.

(b) The metering pump is to be supplied with a manually adjustable stroke length adjustment mechanism for dosage capable of varying the pumping rate from 0% to 100% and provide positive repeatable settings within ± 1% over the dosage range stipulated above.

To accept the automatic pacing signal stipulated above, the metering pump shall be supplied with -

Select either (i) or (ii)

(i) an electromagnetic clutch between the drive motor and the gear reducer with the necessary controls to accept the time-impulse signal directly.

(ii) a variable speed drive unit incorporating an SCR variable speed drive control (suitable for accepting see (24) electrical supply) and a DC drive motor. The drive motor shall be TEFC., with a tachometer-generator attached. The signal from the tachometer generator will be utilized as feed-back by the SCR

controller to provide a speed regulation of
± 1% of actual speed over the required range. Mounted on the SCR control panel will be a hand-auto switch, a potentiometer used to vary the motor speed when the switch is in the hand position, a speed indicator and a flow signal indicator.

Materials of construction of the wetted parts of the metering pump shall be see (25).

The check valves are to be of the ball type and shall be removeable without disconnection of any piping.

There shall be supplied an internal hydraulic relief valve with the pump forming an integral part of the pump, fully mounted and piped into the hydraulic system. This valve shall be set to by-pass hydraulic fluid when the system pressure reaches see (26) psig.

There shall be supplied a back pressure valve mounted and piped onto the metering pump capable of imposing at least see (27) psig. on the discharge of the pump.

The pump drive motor shall be a minimum of see (28) horsepower.

Accessories supplied with the Metering Pump.

(1) The metering pump shall be supplied with a graduated cylinder and ball valve as shown in the attached sketch (refer to Fig. 2.8 in this paper). The valve shall be sized no smaller than the suction connection on the pump. It shall be of PVC and polyethylene construction with the level of liquid in the cylinder capable of being easily seen on the graduated scale. Scale graduations shall be in see (29) gallons and see (30) gallons.

(2) The metering pump shall be supplied with a stand-pipe accumulator and valve as shown on the attached sketch (refer to Fig. 2.9 in this paper). It shall be see (31) ins. dia. X see (32) ins. high and the ball valve shallbe the same size as the discharge connection of the pump. Materials of construction shall be PVC.

The following are examples of data to "fill in the blanks" noted above:

(1) lime slurry

(2) 20%

(3) 80 deg. F.

(4) 35 deg. F.

(5) 3 feet

(6) 8 feet suction lift

(7) 2 foot suction lift

(8) 40 feet

(9) 10 feet

(10) 80 psig.

(11) 150 Igph.

(12) 3500 Igpm.

(13) 150 mg/l.

(14) 500 Igpm.

(15) 50 mg/l.

(16) 21:1

(17) 8 Igph. (approx.)

(18) 4 - 20 ma DC

(19) 4000 Igpm.

(20) 3:1

(21) 3:1

(22) 4-20 ma DC

(23) 575/3/60

(24) 115/1/60

(25) mild steel cylinder, 316 s.s.checks, hypalon diaphragm.

(26) 60 psig. (if discharge is to atmospheric pressure

(27) a back pressure valve is not suitable for slurry - suggest utilizing the accumulator ~~+~~ orifice discussed in Section 2H-V11.

(28) 1 horsepower

(29) 1 gallon increments

(30) 0.1 gallon increments

(31) 4" diameter

(32) 10" high.

(3) Calculating the Maximum and Minimum Feed Rates for the Chemical Feeder.

The following is a step by step procedure for determing the maximum and minimum chemical feed rates with a computation to determine the "range of accuracy" required by a feeder for the system.

The following tables provide a handy reference for determining the pounds of effective chemical per gallon of solution.

Ferric Chloride -

Ferric Chloride solution can be delivered in bulk quantities. The solution strength varies from about 35% to 50%. Dosages are normally expressed in terms of "lbs. of $FeCl_3$".

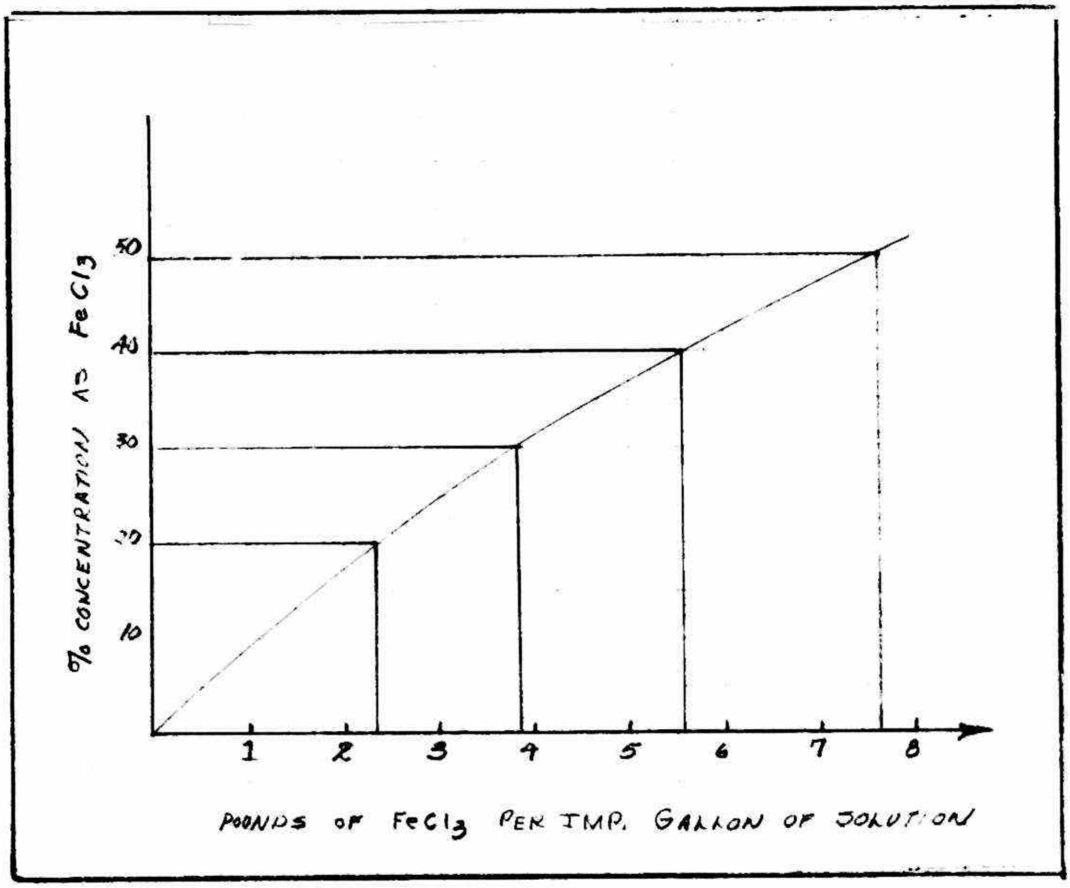


Table 3.1 - Pounds of $FeCl_3$ per Imperial gallon of solution at various concentrations.

Alum -

Liquid alum is delivered in bulk shipments as a 48% solution. There are 6.5 lbs. of standard ground alum per Imperial gallon of this 48% solution. Standard ground alum (SGA) $Al_2(SO4)_3 \cdot 14H_2O$ is the standard 'effective chemical' used to express dosages. If Al+++ ion is used, note that 1 lb. of SGA contains 0.09 lbs. of Al^{+++}.

Lime Slurry -

These slurries are normally made-up in concentrations varying from 5% to 25%. Dosages are usually expressed in terms of lbs. of "$Ca(OH)_2$".

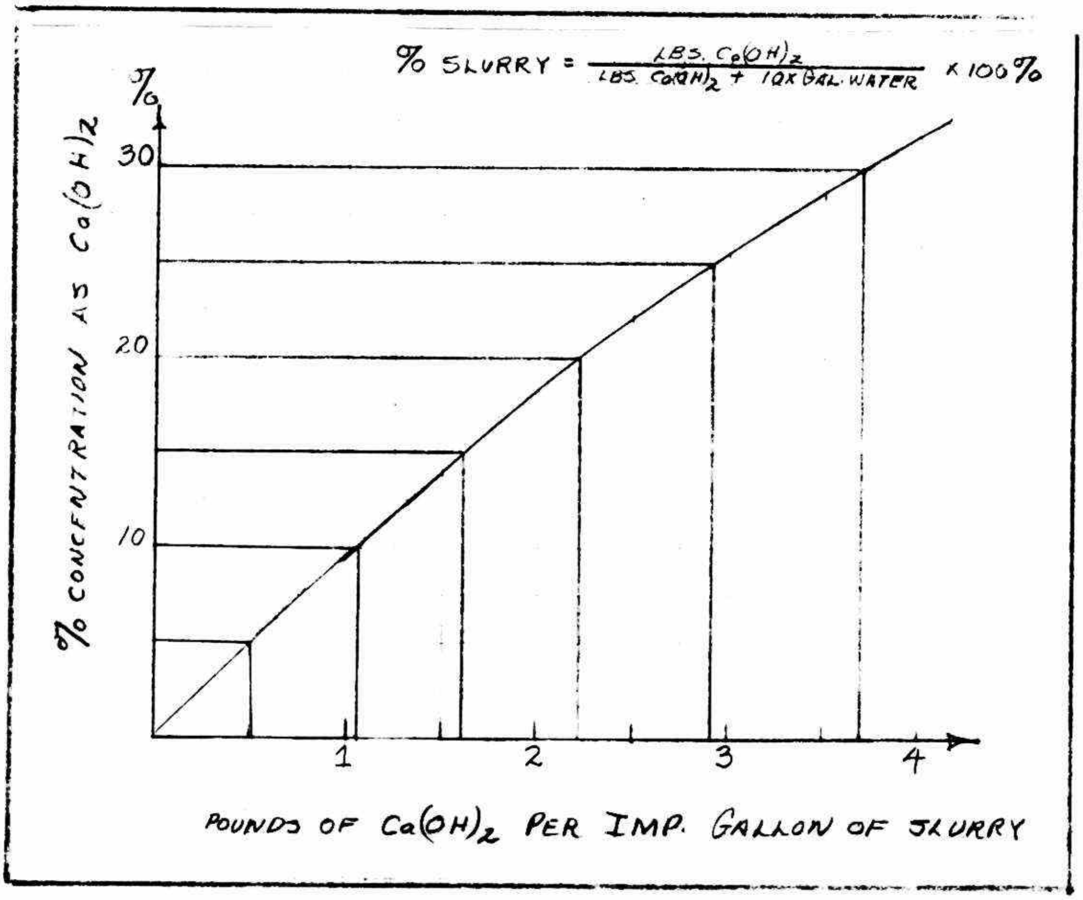


Table 3.2 - Pounds $(Ca(OH)_2$ per Imperial gallon of slurry at various concentrations.

Step by Step Procedure.

(A) Having selected which chemical is to be used for treatment, how many pounds of "effective" chemical (for purposes of simplification this will be referred to as 'EC') are there per Imperial gallon of the chemical solution (or slurry) selected?

Eg. - Alum - standard 48% solution delivered in bulk: lbs 'EC' = 6.5 lbs. of dry filter alum per Imperial gallon of solution.

(B) What are the maximum and minimum dosages of 'EC' in mg/1?

This is normally determined by jar test, pilot plant study or some other chemical analysis. It is important in sizing the chemical feeder to know in advance the maximum and minimum practical chemical dosages that over the course of a year could be encountered. Any maximum to minimum dosage ratios greater than 20:1 should be avoided since the chemical feeder will probably not be capable of providing accurate control when coupling this widely varying chemical dosage with a varying flow to be treated.

(C) What are the maximum and minimum instantaneous flows to be treated?

This is an important point and two situations are to be considered:

(i) Manual Control -If the chemical feed rate is to be set by 'hand' or if the chemical feeder comes 'on and off' with (say) a sewage pump, then the chemical feeder selected need only have one means of capacity control, provided that this one manual control device can vary the chemical feeder output accurately over a wide enough range determined in item (E) below.

(ii) Automatic - Open-Loop Pacing from "Flow".

If the chemical feed rate is to be automatically paced from flow (common situation), then the flow meter initiating the control signal is a limiting item in the control loop and must be looked at carefully. The maximum flow to be treated must be the flow corresponding to the maximum flow signal of the flow meter even though this flow may be higher than any flows to be treated. The chemical feeder must be sized based on this flow signal. In determining how much chemical is to be used, obviously the actual maximum flow would be utilized.

In determining the minimum flow to be treated (as far as pacing the chemical feeder) - select the minimum flow corresponding to the lowest accurate signal sent by the flow meter.

Depending on the manufacturer, most flow meters have a 5 to 1 (some have 10 to 1) flow range from maximum flow capability of the flow meter.

NOTE: - "Instantaneous" flows must be used since the chemical feeder must follow "instantaneous" flow signals.

(D) What are the maximum and minimum chemical feed rates expressed in Imperial gallons per hour?

(i) Maximum chemical feed rate (IGPH).

$$= 1/2.4 \times \underline{\text{Max.}}\ \text{Flow (MIGD)} \times \underline{\text{Max.}}\ \text{Dosage (mg/1)} \times \frac{1}{\text{lbs. (EC) I.G. sol'n.}}$$

(ii) Minimum chemical feed rate (IGPH).

$$= 1/2.4 \times \underline{\text{Min.}}\ \text{Flow (MIGD)} \times \underline{\text{Min.}}\ \text{Dosage (mg/1} \times \frac{1}{\text{lbs. (EC) I.G. sol'n.}}$$

Eg. - Max. Instantaneous Flow = 1 MIGD.
Min. " " = 0.1 MIGD.

Max. Dosage = 150 mg/l.
Min. Dosage = 50 mg/l.

Lbs. (EC) per Imperial gallon of solution = 6.5 lbs.

Max. Chemical Feed Rate -
1/2.4 X 1 X 150 X 1/6.5

= 9.6 IGPH.

Min. Chemical Feed Rate -
= 1/2.4 X 1 X 150 X 1/6.5
= 0.32 IGPH.

(E) What is the "Range of Accuracy"?

$$\text{Range of Accuracy} = \frac{\text{Max. Chemical Feed Rate}}{\text{Min. Chemical Feed Rate}}$$

Eg. - from (D) above -

Range of Accuracy = 9.6/0.32 = 30:1

Dosage Range = 150/50 = 3:1

Flow Range = 1/.1 = 10:1.

(4) Alum Handling. - Also see Section 3.

Liquid Alum is normally supplied in Ontario in bulk loads. A storage tank should be supplied capable of holding at least 1½ loads. This ensures that the tank can accept a load even when it is 1/2 full.

It is recommended that the booklet entitled "Aluminum Sulphate" be obtained from the Allied Chemical Company located in Toronto.

(5) Ferric Chloride Handling. - Also see Section 3.

Ferric Chloride solution is also supplied in bulk loads. Storage tank sizing is the same as suggested for liquid alum.

It is recommended that the booklet entitled "Handling Ferric Chloride" be obtained from the Dow Chemical Company in Toronto.

(6) Dry Feeders.

Dry feeders are now mainly restricted to two chemicals - namely - dry polymers and lime (hydrated or quicklime).

This device, like the metering pump, should be selected carefully. Dry materials however, cannot be"pumped", they must flow by gravity out of storage, through the feeder and into the

(a) "slurry tank" in the case of hydrated lime.
(b) "slaker" in the case of quicklime.
(c) "wetting device" in the case of dry polymers.

A description of the various types of dry feeders is contained in "Lime-Handling, Application and Storage" available from Domtar-Lime Division in Toronto. This text covers these devices so well that a further description is not included in this paper.

(7) Dry Polymer Handling and Solution Preparation.

A system for handling dry polymers is to be selected carefully in order to ensure that the full chemical properties of the polymer are utilized. Many times a polymer has been considered ineffective chemically when, in fact, if it had have been properly wetted mixed and aged, it might have performed well. An improperly prepared polymer solution, or a "too long in storage" polymer solution can be reduced by as much as 90% of its effectiveness.

Dry polymers are normally shipped in bags or drums. To be utilized properly each individual dry particle must be wetted (placed in violent contact with water) such that no two or more particles are touching when the initial contact with water is made. If two or more particles are touching, an insoluble agglomerate ("fish eye") is formed which is chemically useless and can plug pumps, lines, etc. Once these dry polymer particles are properly wetted, they are mixed with a slow speed mixer (400 rpm max.). Concentrations by weight of dry polymer to water in a polyelectrolyte solution are typically 0.5% to 0.1%.

During this mixing cycle, which for most polymers is about 1/2 hour to 2 hours, the polymer "ages" to form a 'reactive' solution. Once the required "age and mix" time is completed, the solution can be either utilized directly from the age and mix tank or can be transferred by gravity (or by a low shear positive displacement transfer pump) to a storage tank from which it then can be utilized.

For an automatic polymer make-up system, a separate 'age and mix' tank and storage tank are utilized. Generally, if polymers are to be utilized at rates greater than 1 lb. per hour, an automatic preparation system should be seriously considered. The tankage and man hours are much less. The heart of the automatic system is, of course, the dry feeder and 'wetting' device. These must be selected very carefully, several bad designs are on the market.

The polymer solution is automatically prepared in a (manually adjustable) constant concentration. The automatic make-up system must be capable of preparing this constant concentration to very close tolerances without 'fish eyes' and without "down time".

Note - Manual methods of polymer solution make-up are well documented and will not be presented in this paper.

For automatic systems, it is recommended that the "age and mix" tank be sized as follows:-

$$A.M.T = \frac{1}{60} \times A.T. \times M.U.R. + (\text{fill time} + \text{empty time}) \frac{M.U.R.}{60}$$

A.M.T. - Age and mix tank size (gallons)

A.T. = Max. age time required by polymer. (minutes).

M.U.R. = Max. use rate of polyelectrolyte solution (gph).

Fill time and Empty time are in minutes.

Polyelectrolyte solutions start losing their effectiveness as soon as they are properly 'aged'. It is important therefore, to utilize them while they are still effective. Maximum storage time is recommended to be 2 to 5 days. Generally, the storage tank can be sized to contain one day's normal use.

"Deterioration rate" is effected by the following: -

Temperature - the higher the temperature, the faster the deterioration.

pH - A pH of 7 is preferred, above 7 deterioration is rapid.

Make-up Concentration - the higher the concentration the more stable.

The metering and pumping of the polyelectrolyte solution to the point of application is normally performed by a metering pump. Unless wastage of polymer can be tolerated, a high accuracy pump as described in Section 2 of this paper should be utilized.

The metering accuracy of the pump feeding this polyelectrolyte solution is vitally important. For a vacuum filter application - too little polymer and the filter blinds, too much polymer and it won't pick up the sludge. For a centrifuge, too little polymer and the centrate is dirty, too much and polymer is wasted.

It is recommended that the polyelectrolyte solution be diluted (up to 1/40th % concentration) before being introduced to the treatment system. To achieve this, water can be introduced into the polymer solution close to the discharge of the metering pump as shown in Figure 7.1 - on next page.

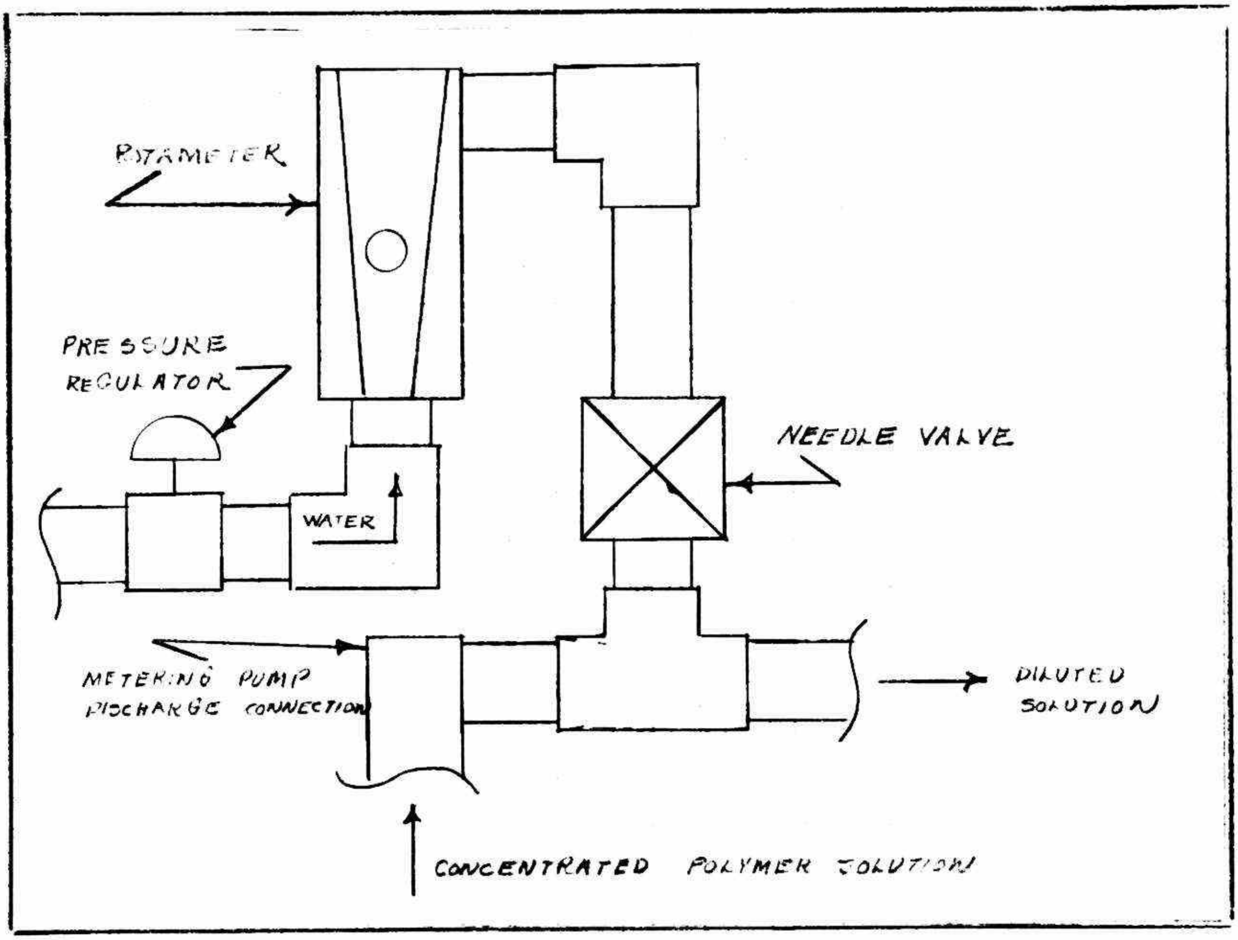


Fig. 7.1 - Dilution Water Piping.

Generally two cirteria are to be followed in designing a polymer handling system. -

(1) design a maximum of flexibility.

(2) metering accuracy is vital.

(8) <u>Lime Handling</u>. - Also see Section 3.

The handling and feeding of lime is covered by another paper being presented at this Seminar.

As mentioned in Section 6, a very useful and complete text on lime - both hydrated and quicklime is - "Lime-Handling, Application and Storage" and is available from Domtar-Lime Division in Toronto.

USE OF LIME FOR PHOSPHORUS REMOVAL

B. P. Le Clair

and

E. Ladouceur

Wastewater Technology Centre,
Canada Centre for Inland Waters,
Burlington, Ontario.

Presented at the Phosphorus Design Seminar,

May 28, 29, 1973,

Toronto, Ontario.

USE OF LIME FOR PHOSPHORUS REMOVAL

PURPOSE

The technology for removal of phosphorus from wastewater has developed rapidly in the last few years. The need for practical phosphorus removal procedures is a result of the over-fertilization and eutrophication of the country's surface waters. This further resulted in the establishment of water quality standards that limit the concentration of phosphorus entering the receiving waters.

Research and demonstration studies at several cities in the past few years have been undertaken to advance the knowledge of phosphorus removal. This paper is intended to summarize process design information and operating experience on the use of lime, including the direct use of dry unslaked lime for phosphorus removal.

SCOPE

The paper is concerned with the use of lime for phosphorus removal. Process design information and operating experiences are presented. Comparisons of the lime handling methods are presented and recommended methods are demonstrated. Details of the lime itself (solubility, heat of reaction, and other chemical properties) are not presented. Similarly, specific details of equipment and equipment alternatives are not presented. This information may be found in one of several books and papers explicitly written to serve as a guide to designers and operators of water, sewage and chemical process plants. (Table 1).

TABLE 1

REFERENCE MATERIAL FOR DESIGNERS OF LIME SYSTEMS

Lime, Handling, Application and Storage, Bulletin 213, National Lime Association, (May, 1971)

Chemistry and Technology of Lime and Limestone, R. S. Boynton, John Wiley and Sons, (1966)

Chemical Treatment of Sewage and Industrial Wastes, W. A. Parsons, Bulletin 215, National Lime Association, (1965)

Process Design Manual for Phosphorus Removal, Black & Veatch, Consulting Engineers, U.S. Environmental Protection Agency, (1971)

Lime - Storage, Handling and Feeding, T. Fahlenbock, Water and Pollution Control, 111, (3), 39 (1973)

Unslaked Lime - Its Direct Use in Water Treatment, F. L. Ward, Water and Wastes Engineering, December 1965

Dry Feed of Ground Quicklime Without a Slaker, A. A. Hirsch, Journal American Waterworks Association, December 1962

- - - - - - - - - - -

BACKGROUND

The addition of lime to raw wastewater for the purpose of phosphorus removal has been practiced at a number of plants. Removal of the phosphorus in primary treatment is accompanied by increased BOD and suspended solids removal and thereby reduces the organic load on the secondary treatment facilities. Reduced organic load benefits overloaded plants and also aids in establishing nitrification. Other possible benefits include improved oil, grease and scum removal and less corrosion of the primary sludge handling system.

The main disadvantage to lime usage for phosphorus removal expressed in the literature has been the increased volume of primary sludge which results. For most primary plants, it is anticipated that the sludge produced in the primary will be three times normal. This is not as bad as it seems as one half of the increased sludge volume can be attributed to increased suspended solids removal. Also, as the load to the activated sludge section of the process is reduced by about 50% with lime treatment, the quantity of waste activated sludge, which is difficult to dewater, is reduced accordingly.

METHODS OF LIME HANDLING

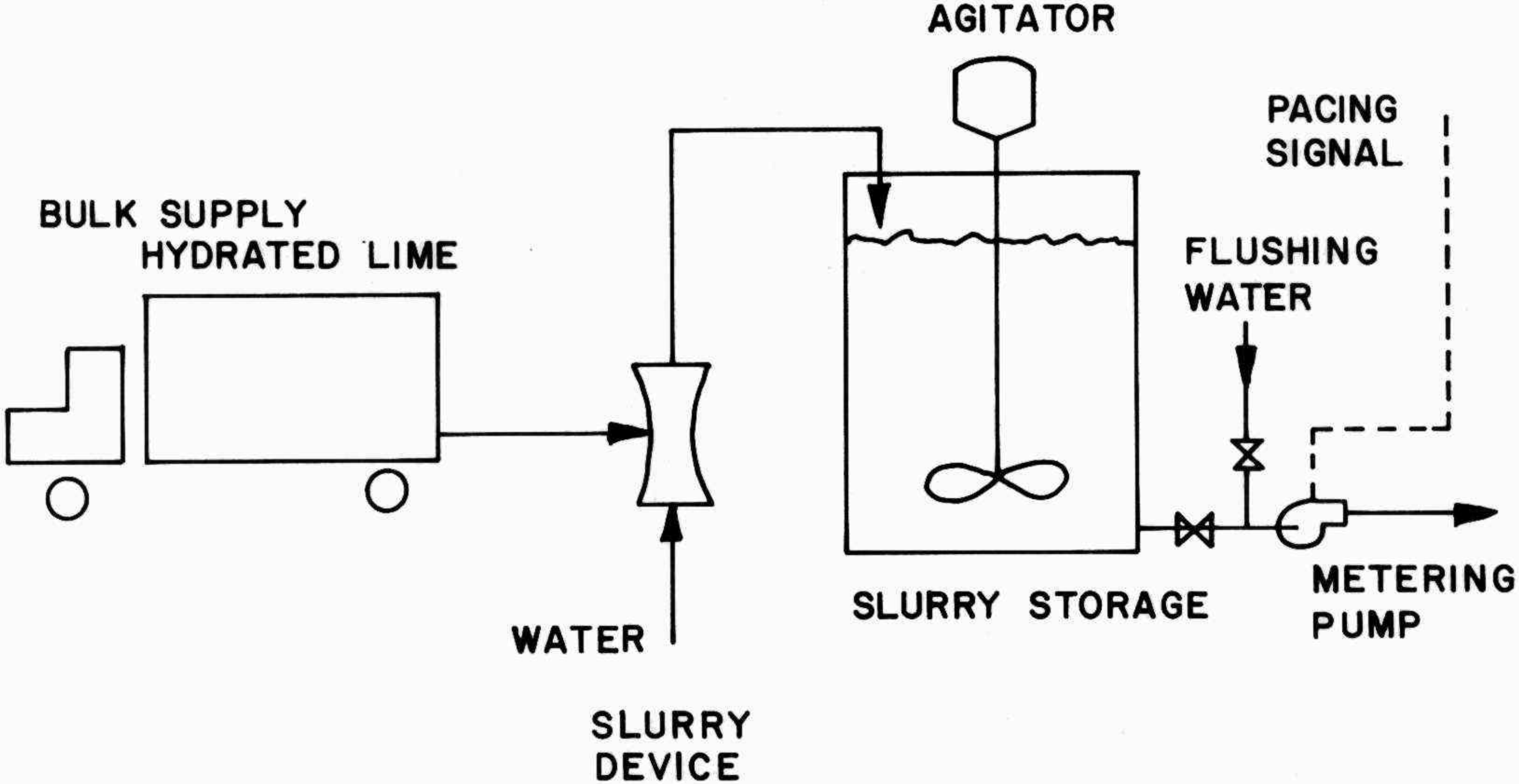
The method of storage and feeding of lime as presented, practiced at full scale or at pilot scale, is one of three possible methods: bag or bulk hydrated lime batch slurry make-up, storage and controlled rate feeding; dry hydrated lime bulk hopper storage, batch continuous slurry make-up and controlled rate feeding; and dry quicklime bulk hopper storage, slaking, slurry storage and controlled rate feeding.

SLURRY STORAGE AND CONTROLLED RATE FEEDING

Storage and handling for small plants has involved bulk or bag hydrated lime batch slurry make-up, storage, and controlled rate feeding. This method is practiced at Newmarket, Ontario, and is shown schematically in Figure 1. At periodic intervals, normally every two or three weeks, a batch of slurry is made up by mixing the dry lime hydrate with water in the slurry storage tank. Nominally, the lime is made up as a 20-25 wt % slurry of calcium hydroxide and approximately 900 I gal of slurry storage is required per MIGD. As dry hydrate is most economically delivered in bulk in 20-ton quantities, storage tanks of 17,000 I gal or larger are required. Sizing and mixing requirements for several possible tanks are presented in Table 2.

When slurry operation is carried out in the above manner, additional mixer horsepower is required during slurry make-up. The agitator horsepower requirement is almost doubled. Lime dust problems are also encountered. Also, a small auxiliary lime storage tank is required for use when slurry is being made up in the main tank. These problems can be overcome by using a continuous slurry device. Such a slurrying device is the Halliburton Jet-Slurries Mixer. The mixer has a capacity of about 200 I gal/min and can process about 20 tons of dry lime hydrate in about 2 hours, producing a dustless slurry. In the process, water at 70 psi pressure is required. Slurry make-up, using the device, has been carried out with some success at several plants in Ontario - namely - the Markham Sewage Treatment Plant and the Tottenham and Waterford Lagoons.

The slurry is pumped from the storage tank to the point of



LIME STORAGE AND HANDLING – BATCH SLURRY MAKE-UP

FIGURE I

TABLE 2

SLURRY STORAGE TANK REQUIREMENTS

FLOW MIGD	STORAGE TONS	TANK SIZE FT^3	I GAL	SQUARE	CYLINDRICAL	MIXER HP
1	20	2800	17,000	14 ft	15 ft Ø x 15 ft	8
2	30	4200	26,000	16 ft	20 ft Ø x 15 ft	13
3	45	6300	40,000	18-1/2 ft	20 ft Ø x 20 ft	20
5	60	8400	52,000	20 ft	2-20 ft Ø x 15 ft	2-13

application as needed, via a metering pump (normally a positive displacement pump). With lime slurries, certain precautions with respect to pump and piping design should be exercised. They include:

1) Back pressure (non-siphoning) devices cannot be used as they plug readily. Thus, the exit point for the slurry must be such that siphoning cannot take place. (Applies to positive displacement pumps which employ check valves, progressing cavity pumps (such as Moyno) are not subject to this condition.
2) Abrasion damage to pumps and impellers from grit in the slurry, scaling by calcium carbonate, or settling out of lime in stagnant pockets necessitates a rigid schedule of inspection. Pumps should be opened and dismantled weekly.
3) The pump and piping system should be designed with a fresh water flushing mechanism. Pumping systems should be flushed daily to maintain control on sludge and scale build-up.
4) The slurry should discharge through an air gap at the point of application to prevent scale formation.

BULK DRY LIME HYDRATE STORAGE

The second method of feeding lime employs dry hydrated lime bulk hopper storage, batch-continuous slurry make-up and storage and controlled rate feeding to the point of application. Considerable savings with increased plant size over the slurry method can be effected by this method of lime handling owing to the reduced labour cost involved in handling the product. In addition, there are other advantages, including faster unloading, elimination of losses from spillage, better house cleaning since modern

handling systems are completely enclosed, and less hazard to employees.

The technique is being practiced on a trial basis in Ontario using a number of moveable package demonstration lime handling facilities. Sewage treatment plants which have tested or are testing the facility include the following:

1.	Owen Sound	-	(MOE)
2.	London	-	(M. M. Dillon)
3.	Wallaceburg	-	(LaFontaine - MOE)
4.	Caledonia	-	(D. Wilson)

The dry feed storage system employs four main components: 1) a storage hopper, 2) a dry feed element, 3) a mixing pot or solution tank and 4) a slurry pumping and metering device.

The storage hopper may consist of one or more storage units. The total storage capacity should be at least 50% greater than the minimum truck delivery. Reserve capacity should be such that at least seven days' but preferably fourteen days' supply is on hand at all times. The silo must be designed to handle the erratic flowability of dry hydrated lime. Lime tends to absorb moisture readily, forming an adherent soft cake which can cause arching or bridging in storage. It also tends to form rat holes, craters or chimneys, due to its fluffy texture and possibly electrostatic charges. Then, after collapsing, the lime hydrate may become fluidized, thus flooding the discharge opening.

Owing to the inherent problems in the flowability of lime, several design factors have been developed to facilitate operation. They include:

1) Bin construction should be such that internally the tank is free of

any features which could resist material flow and cause build-ups.

2) A height/diameter of 2-1/2 - 4 is desirable.

3) The hopper bottom should have a minimum slope of 60 degrees from the horizontal.

4) The hopper should also include a dust collector, pneumatic hook-up line, manual bin gate (valve) and a fail-safe pressure relief system.

5) The hopper should also include one or more hopper agitation devices. For hydrated lime, air jets and pulsating air pads should be used to aid the flow - the air serving to fluidize the hydrate. The jets and pads should only be operated when lime is being fed from the hopper.

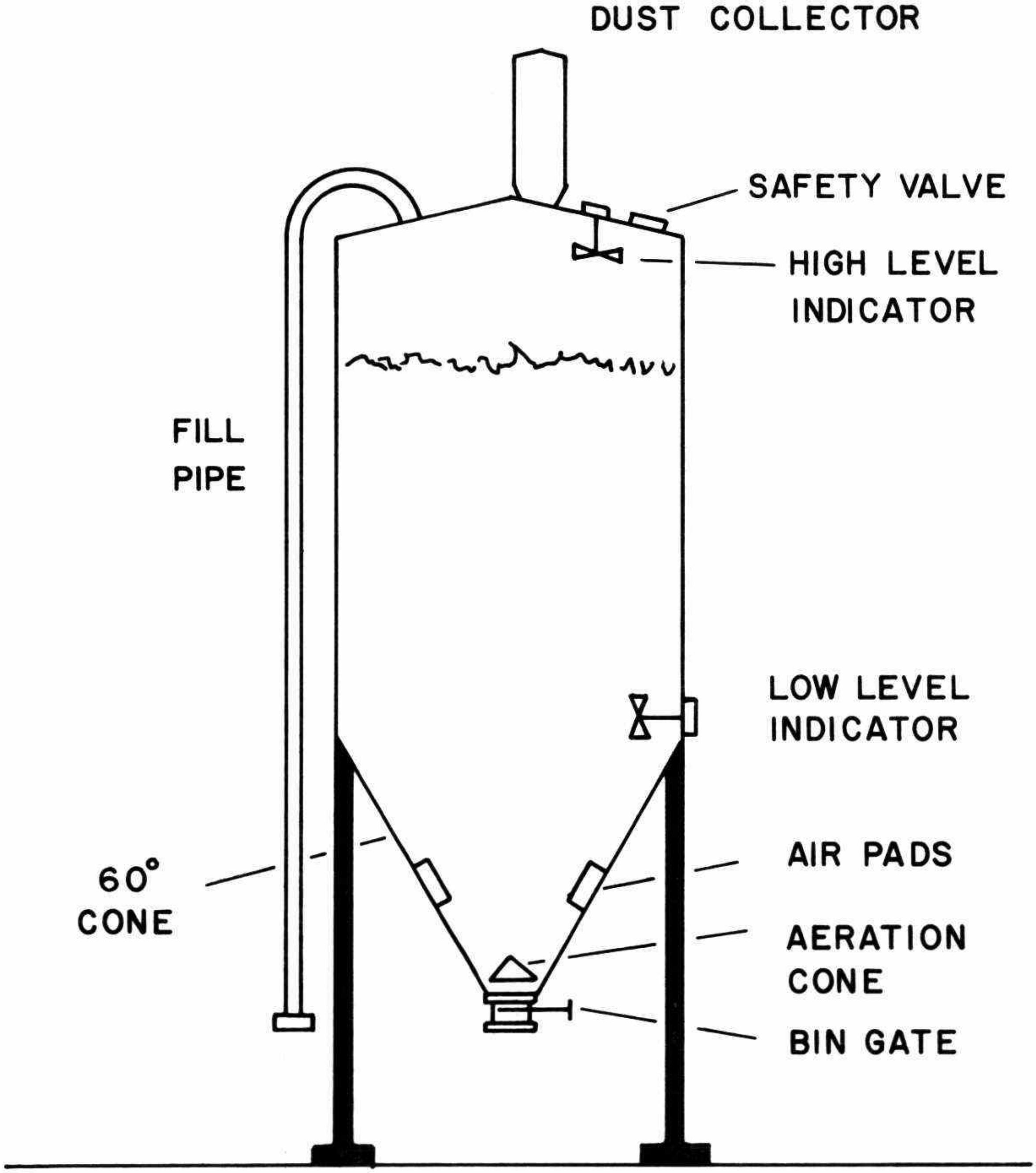
A schematic diagram of a typical storage hopper is presented in Figure 2.

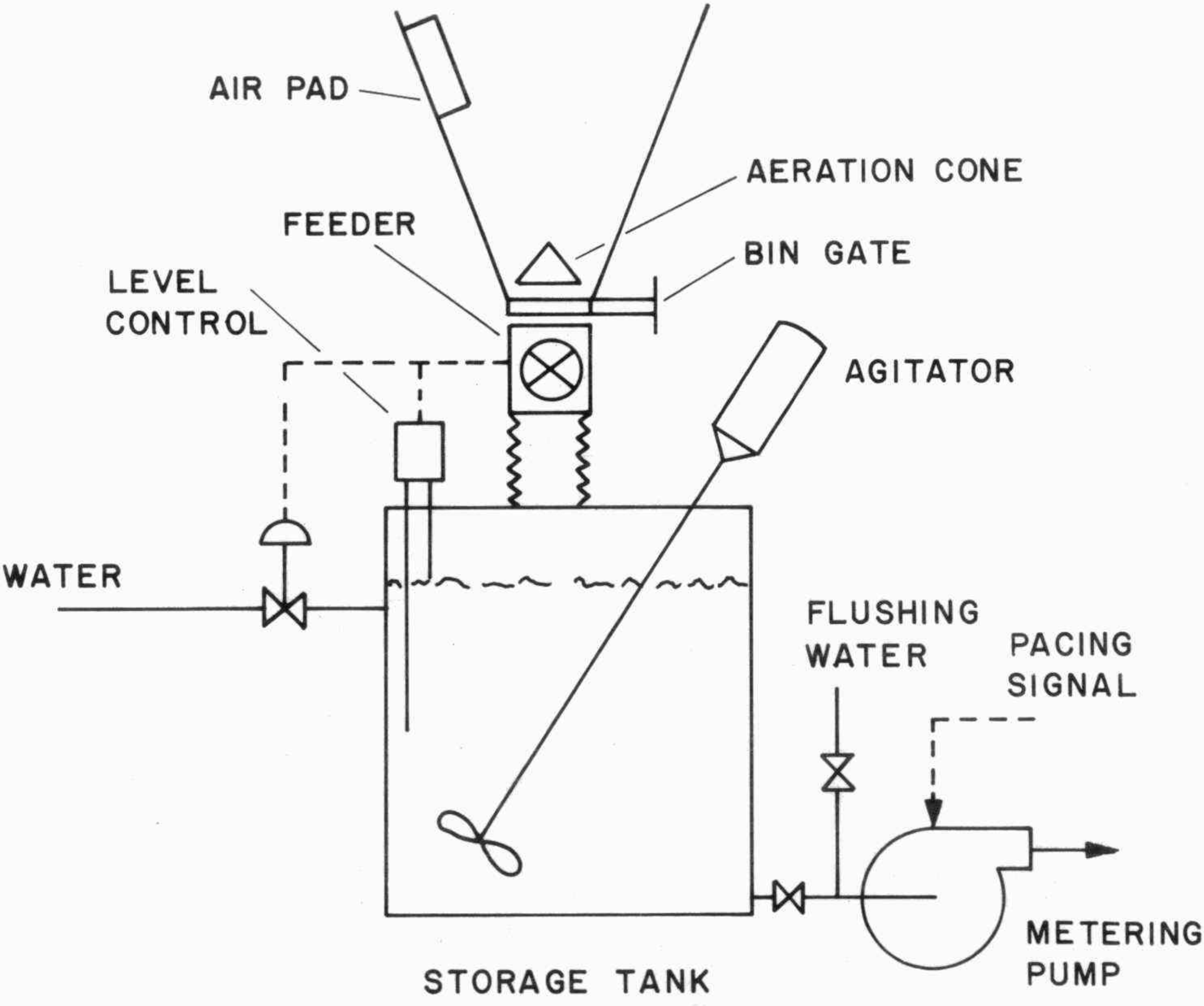
The second component of the dry feed system is the dry feed metering element. This element may be one of two types: a volumetric feeder (dispensing chemical on a volume basis)or a gravimetric feeder (dispensing chemical on a weight basis). Volumetric feeders are cheaper and more inaccurate than gravimetric feeders; however, they are less complicated and more robust and thus require less maintenance and are more trouble-free. Owing to these last two factors and the erratic behaviour and scaling of lime, volumetric feeders are recommended. As lime has a variable bulk density, periodic recalibration of the volumetric feeder is required (twice a week).

Although the main function of the feed element is to dispense chemical, it also incorporates a number of other features. These stem from the poor flowability of lime. The device must be able to handle a

FIGURE 2

BULK STORAGE HOPPER





DRY HYDRATED LIME BULK FEED SYSTEM

FIGURE 3

flooding situation. Secondly, the feeder must be constructed in such a way that moisture (either water or wet air) cannot get into the silo. Finally, the feeder must be designed so that splashings from the solution tank located below the feeder will not cause scaling of the feed element.

The third and fourth features of the feed system, the solution tank and metering pump are similar to that for the slurry feed system. A schematic presentation appears as Figure 3. The unit operates as a batch-continuous unit. The dry lime hydrate and slurrying water do not vary and are fed into the slurrying device in constant proportion to one another. Level controls in the slurry storage tank operate a solenoid valve on the slurrying water supply and "on-off" control of the dry feeder. The constant strength slurry in the storage tank is fed to the point of application by a slurry feeder which is automatically paced from the flow signal.

BULK DRY QUICKLIME STORAGE

The third method of feeding lime employs dry quicklime bulk hopper storage, batch or continuous slaking, slurry storage and controlled rate feeding to the point of application. Considerable savings can be realized through the use of quicklime instead of hydrated lime. The theoretical ratio of calcium oxide in quicklime to that in hydrate is 1.33 to 1.0, or, stated in another way, 75 lbs. of quicklime should do the same job as 100 lbs. of hydrate. Quicklime is also 10 percent cheaper per pound than hydrated lime. Other benefits may be derived from the use of quicklime which may outweigh those of cost saving. They are related to the improved flowability of quicklime when compared with hydrated lime.

A series of studies under the Canada/Ontario Agreement are in progress on the use of quicklime for phosphorus removal. They include the following:

1) Pilot scale evaluation of quicklime use for phosphorus removal -- experimental study at the Wastewater Technology Centre (completed May, 1973).
2) Determination of the most economical and reliable method of handling quicklime for phosphorus removal -- engineering study by T. Fahlenbock, Control and Metering (April - August, 1973).
3) Full-scale demonstration of phosphorus removal using quicklime - experimental study at C.F.B. Borden (September, 1973 to March, 1974).

The design of a chemical handling system for quicklime depends upon three factors:

1) physical and chemical properties of the quicklime;
2) slaking method, and
3) method of ultimate disposal of the grit.

These factors are discussed briefly below.

Physical and Chemical Properties of Quicklime

Lime in its various forms, as quicklime and hydrated lime, is the principal, lowest cost alkali. Quicklime is a product resulting from the calcination of limestone. It consists primarily of the oxides of calcium and magnesium. The physical and chemical properties of quicklime affect its slaking rate and the nature of the hydrated lime formed. On the basis of chemical analysis, quicklime can be divided into three classes:

high calcium quicklime	- less than 5 percent magnesium oxide,
magnesium quicklime	- 5 to 35 percent magnesium oxide,
dolomitic quicklime	- 35 to 40 percent magnesium oxide.

Quicklimes may also be classified on the nature of the calcining process:

hard-burned	- calcined at high temperature and generally characterized by relatively high density and moderate to low reactivity,
soft-burned	- calcined at relatively low temperature and characterized by high porosity and reactivity.

Almost all of the lime available in Ontario is high calcium quicklime; however, it may be hard or soft-burned. The material is available in a number of more or less standard sizes:

pebble lime	- ranges in size from 3/4 to 1/4 inches, produced in most kilns,
crushed	- ranges in size from 1/4 inch to dust,
ground	- product resulting from grinding the larger size material and/or screening of the fine size,
pulverized	- product resulting from intense grinding.

Slaking of Quicklime

The term "slaking" applies to the combining of varying proportions of excess water and quicklime to produce a hydrated lime slurry. For maximum efficiency, the lime should be slaked at or near optimum conditions. These conditions are normally determined by testing. However, the way the lime is slaked can mean the difference between a slaked lime of very

minute average particle size, high surface area, and porosity that is slow settling and chemically very reactive and another hydrate that is much coarser, possibly incompletely hydrated, that settles rapidly and has slow reactivity. The variables which affect slaked hydrate quality are:

- reactivity of the quicklime,
- particle size and gradation of the quicklime,
- amount of water,
- temperature of slaking,
- distribution of water,
- agitation.

The slaking process is carried out in a device called a slaker, which may be one of two basic types (1) detention type - which produces a lime slurry or (2) paste type - which produces a paste or putty, the only real difference between the two being the amount of water initially added to the quicklime. In wastewater treatment plant operations, the detention type is preferred. Within a detention slaker, there are nominally two compartments. The reaction takes place in the first compartment where the dry quicklime is mixed with the optimum amount of water at the desired temperature. The high solids hydrated lime slurry produced passes to a second compartment where dilution water is added to produce a slurry of the desired consistency. This chamber also contains the degritting device.

The gritty residue from the slaking process is probably the main reason the use of quicklime, rather than hydrated lime, is not used universally in wastewater treatment operations. With high-quality chemical

quicklimes that have been thoroughly calcined and have a loss-on-ignition of 1-1/2 percent or less, the grit content that must be wasted is 1 - 2 percent of the weight of the quicklime. Included in the grit, along with the carbonate core, are insoluble silicates, etc., all impurities occurring in the limestone. The grit resembles a mass of wet sand-like particles of size ranging from 1/4 inch to 100# mesh. Degritting is performed to improve lime quality and reduce abrasion and wear on equipment.

Pilot scale Testing of Quicklime for Phosphorus Removal

In 1972, under the Canada/Ontario Agreement, a pilot plant program was instituted to study the direct use of quicklime for phosphorus removal. The study was carried out at the Wastewater Technology Centre where a 20 I gal/min primary treatment plant, with a quicklime/dry hydrated lime chemical addition system, was built. The study had several objectives. They include:

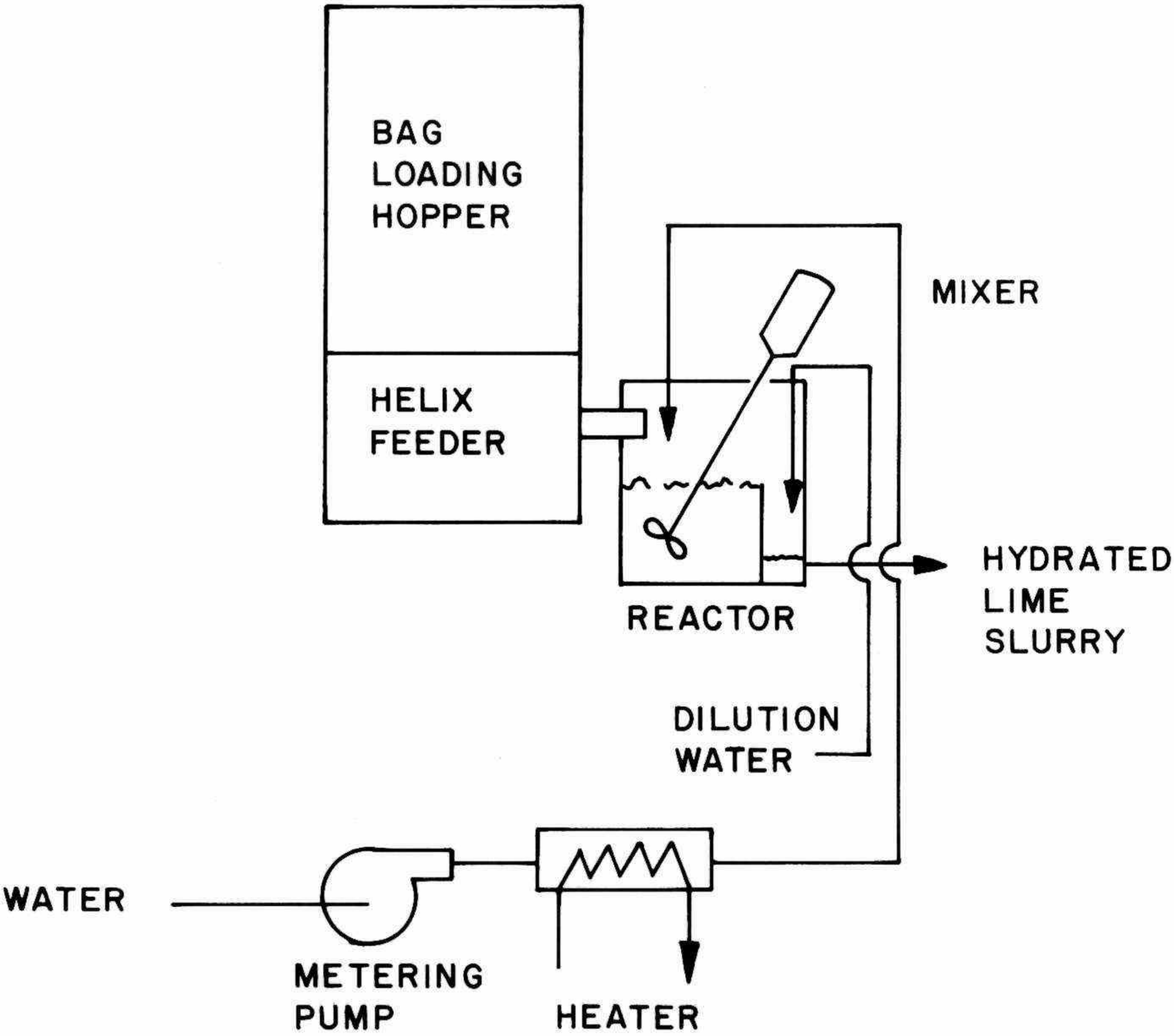
1) that hydrated lime of the desired quality may be efficiently produced from ground quicklime in a simple reactor;

2) that the lime produced would yield phosphorus removal characteristics equivalent to commercially available hydrated limes;

3) to produce a design for full-scale equipment based on the process developed.

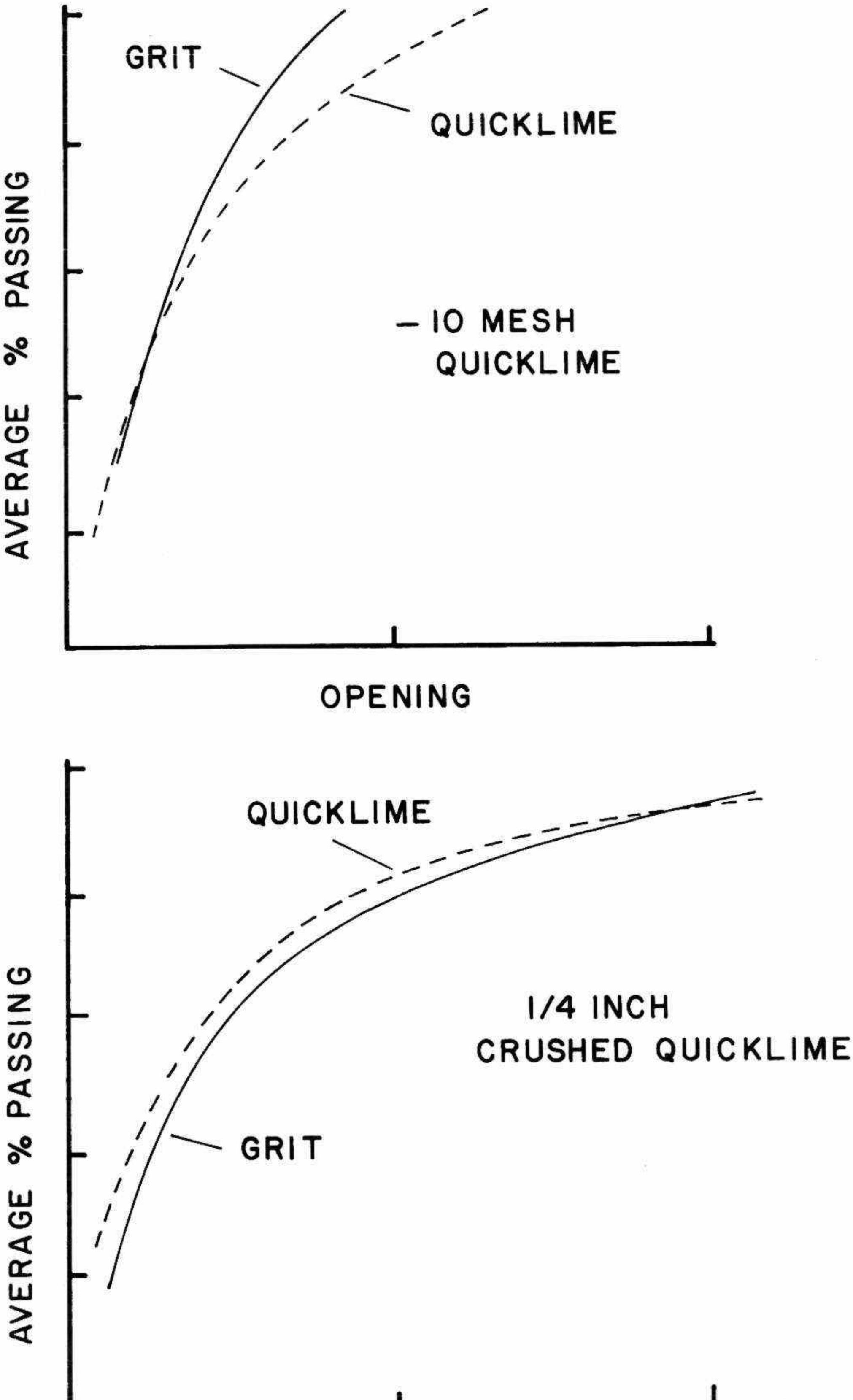
The pilot plant (Figure 4) which was built has been operated successfully for approximately 10 months using a variety of pebble and ground quicklimes. These quicklimes, which were supplied by Domtar Chemicals, are as follows:

Beachville rotary crushed	(-1/4 inch to dust),
Beachville rotary kiln ground	(-10 mesh), and
Beachville shaft pulverized	(-28 mesh).



PILOT SCALE QUICKLIME HANDLING SYSTEM

FIGURE 4



GRIT SIZE ANALYSIS

FIGURE 5

Based upon the experimental results, the following conclusions were drawn:

- to achieve the same pH, 1.3 times more hydrated lime is required than quicklime,
- equivalent total phosphorus, soluble phosphorus, biochemical oxygen demand and suspended solids removals were obtained with hydrated lime and slaked quicklime,
- sludge production rates were similar,
- all quicklimes tested will feed satisfactorily from conventional dry feeders,
- instances of arching and flooding from the chemical hopper were lessened considerably when quicklime was used,
- air slaking was lessened and handling difficulties were reduced as the particle size of the quicklime increased,
- grit problems increased with increasing quicklime particle size (Figure 5). There was approximately one pound of grit for every 100 pounds of quicklime. Grit from the minus 10 mesh and minus 28 mesh quicklime was not a problem as it passed to the process with the hydrated lime,
- no problems were encountered with slaking the material in the solution pot. The optimum conditions were as follows:

  reaction temperature 140 - 180°F, water/quicklime ratio (weight basis) 10 - 15, detention time in slaking reactor 20 - 30 minutes,
- build-up of lime on side walls of the solution pot reduced when quicklime was used. Some cleaning needed.
- dust problems reduced with quicklime.

Proposed Design of a Quicklime Chemical Feed System

Based upon the experimental results of the pilot plant program, a design for a quicklime chemical feed system has been developed. The unit encompasses the following features:

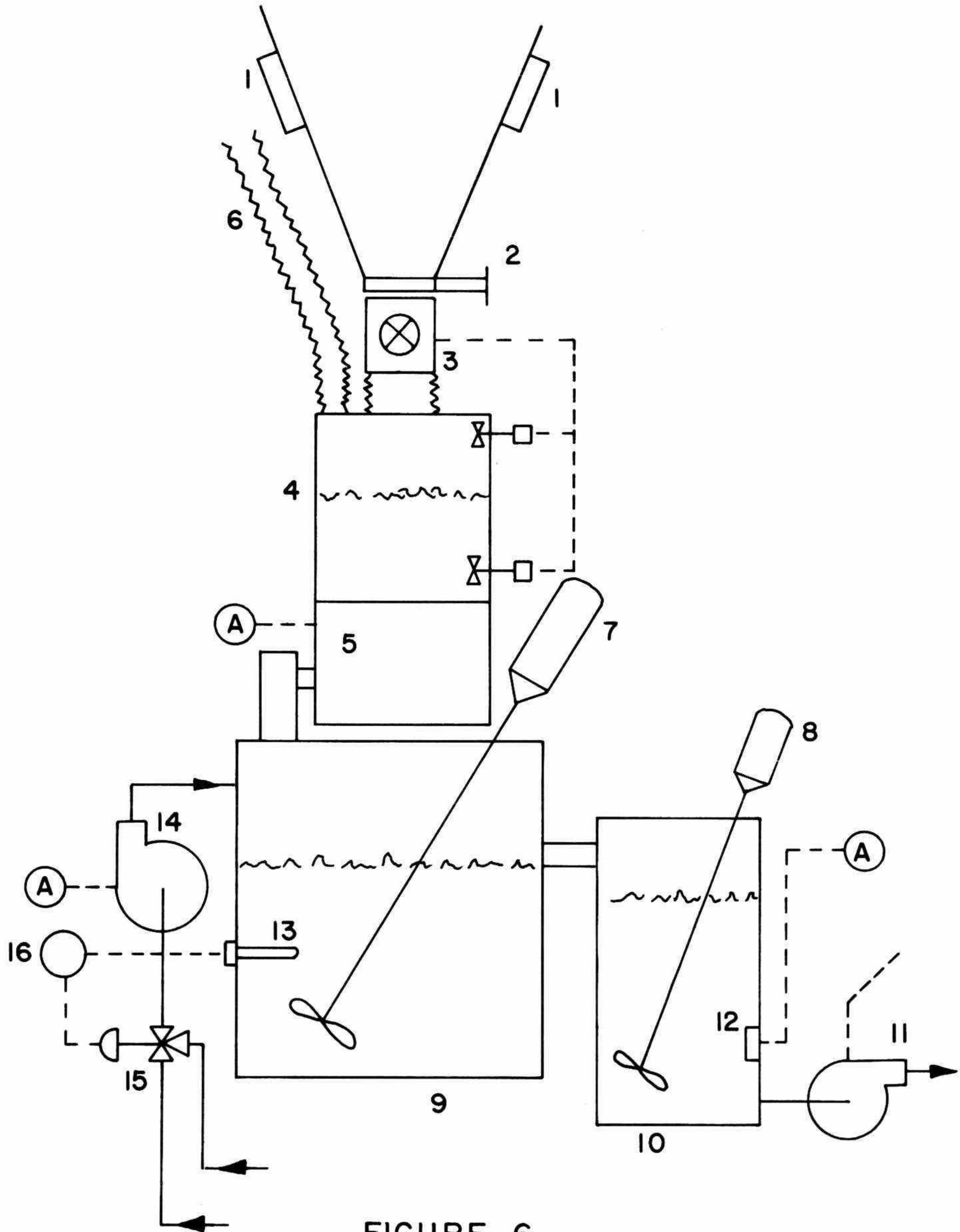


FIGURE 6

GROUND QUICKLIME BULK FEED SYSTEM

- bulk storage of minus 10 mesh quicklime,
- fixed volume reaction tank,
- temperature controlled reaction chamber,
- dry quicklime feeder and water metering pump locked in a fixed ratio to one another. Proportional control of these coupled units from the level in a secondary feed tank,
- controlled flow of the slurry from the secondary tank using a metering pump paced on waste water flow,
- control parameters as determined in the pilot plant program.

A sketch of such a process is presented in Figure 6. The legend for the Figure is as follows:

1) vibrator,
2) bin gate,
3) pre-feeder,
4) primary feeder hopper storage,
5) primary feeder,
6) primary feeder hopper vent,
7) mixer,
8) mixer,
9) reaction tank,
10) secondary storage tank,
11) metering pump paced by wastewater flow,
12) primary sensing element for level,
13) primary sensing element for temperature,
14) metering pump for water,
15) final control element for temperature, and
16) temperature control unit.

SUMMARY

Three methods of handling lime have been presented. The best method at this time, of the methods demonstrated at full scale, is dry hydrated lime storage in a silo and batch continuous slurry make-up. Provided there are no difficulties encountered at full scale with quicklime, and none are anticipated, this method will probably become the preferred method. Approximately 25 percent chemical cost saving should be realized with the method as well as fewer operating difficulties.

- - - - - - - - -

PLANT PERFORMANCE COMPARISON

	AVERAGE RAW SEWAGE	QL	HL	QL SLUDGE	HL RECYCLE	QL	HL
PH	7.5	9.5	9.5	9.5	9.5	11.2	11.2
BOD_5 MG/L	85	54%	46%	58%	70%	78%	74%
SS MG/L	130	35%	40%	62%	69%	74%	60%
VSS MG/L	95	17%	20%	74%	78%	88%	81%
PHOSPHORUS TOTAL MG/L	4.1	69% 0.8	56% 1.2	59% 2.0	67% 1.8	91% 0.3	87% 0.4
PHOSPHORUS SOLUBLE MG/L	2.3	66% 0.5	56% 0.8	68% 1.1	73% 1.0	91% 0.2	89% 0.2

SLUDGE HANDLING, TREATMENT AND DISPOSAL

ACTIVATED SLUDGE CHARACTERIZATION AND SETTLING

by

Ronald Zaloum, Eng.
Environmental Protection Service

May 28, 1973

Although gravity separation and thickening are widely used processes for the removal of solids from biologically treated wastewaters, there seems to exist little information in the literature concerning the fundamental aspects of sludge sedimentation. Clarifier areas are generally determined by use of batch tests, and several methods are used for the estimation of design criteria.

Eckenfelder and Ford (1970) presented a method of developing basic design criteria for secondary clarifiers. The method is based on the approach of Talmage and Fitch (1955) and is essentially one of performing settling tests in one litre graduated cylinders at several initial concentrations. The sludge would be obtained from bench scale pilot plants and conditions presumably altered to achieve these solids levels. The clarification area is determined by graphical construction. Another technique of determining areas is based on the dilution method developed by Coe and Clevenger (1916). This method is still used with little modification. Rich (1971) presents still another method of determining areas, based on the work of Talmage and Fitch (1955). However, he differentiates between the clarification capacity and the thickening capacity of a settling tank. The determination of the clarification area is based on overflow rates while the thickening area is based on the time required to achieve a predetermined underflow concentration. The selection of a clarifier size would thus be based on the largest area of the two.

In all of these methods, it is assumed that settling is only a function of the local solids concentration, and little concern is given to the structural properties of the material under consideration.

This study is a portion of a sludge dewatering and reduction project aimed at the characterization of sludges with respect to physical, chemical and biological properties and the correlation of these properties with various process units. The overall objective of the work is to primarily develop an understanding of sludge dewatering, either by sedimentation or filtration and hopefully to develop design criteria and methodologies for the selection of various process units based on knowledge of the influence

of physical, chemical and biological properties on performance.

The purpose of this paper is partly to present and discuss some of the progress achieved in this area, and partly to evaluate the methods presently employed for the determination of clarifier areas. Only typical results are presented as the data from all tests yielded similar trends.

In this study the height of the subsiding interface was monitored as a function of time. Concentration and aggregate densities profiles were obtained during the course of settling.

Experimental Procedures:

Settling tests:

A 6 inch, 8½ foot high, settling column fitted with 14 ports was employed for all runs. The activated sludge was obtained in the morning from the Skyway extended aeration treatment plant in Burlington, Ontario. Twenty gallons of sludge were siphoned from the aeration tank into a holding tank and brought immediately to the laboratory. The settling column was placed under seven inches of vaccuum and the sludge was allowed to flow through the drain valve. This method was thought to least destroy the flocs. The contents of the column were gently mixed using four inch diameter perforated discs attached in series. Immediately after the discs were removed from the column, three samples from different locations in the column were withdrawn and analyzed for suspended solids. During the course of settling, samples were drawn off, two inches below the interface to ensure the withdrawal of a representative sample. The samples were analyzed for suspended solids and aggregate densities. The densities of dry solids was measured on initial samples.

Suspended Solids:

The suspended solids were done in accordance with the procedure outlined in "Standard Methods,"(1971) .

Dry Solids Densities:

The density of dry solids was obtained using the following equation:

$$\rho_s = \frac{\rho_w}{1 - \frac{\Delta W}{S.S.}}$$

Where ρ_s = density of dry solid, gm/cc

ρ_w = density of water at the sludge temperature, gm/cc

ΔW = weight of suspension - weight of an equivalent volume of water at the sludge temperature, gm

S.S. = total solids content in suspension, gm

The method of total residues as outlined in "Standard Methods", (1971), has been employed, since dissolved solids influence the weight of the suspension.

A 25 mls calibrated density bottle was used, and the solids analysis was done on the contents of the bottle. A large sample of the initial suspension was allowed to settle and the supernatant discarded. The concentrated sludge was employed in the determination. The above equation has been derived as follows:

$$\rho \text{ suspension} = \rho \text{ solid}(\varepsilon \text{ solid}) + (1 - \varepsilon \text{ solid})\, \rho \text{ water}$$

Where ε solid = volume fraction of dry solids

ρ solid = dry solids density gm/cc

$$\varepsilon \text{ solid} = \frac{\rho \text{ suspension} - \rho \text{ water}}{\rho \text{ solid} - \rho \text{ water}} = \frac{C}{\rho_s}$$

$$C\rho \text{ solid} - C\, \rho \text{ water} = \rho \text{ solid}\, (\rho \text{ suspension} - \rho \text{ water})$$

$$\rho \text{ solid} = \frac{C\, \rho \text{ water}}{C - (\rho \text{ suspension} - \rho \text{ water})}$$

$$= \frac{\rho \text{ water}}{1 - \left(\frac{\rho \text{ suspension} - \rho \text{ water}}{C}\right)}$$

Multiplying $\dfrac{\rho \text{ suspension} - \rho \text{ water}}{C}$ by $\dfrac{V}{V}$

Where V = volume of density bottle, mls

C = solids content, gm/cc

ρ suspension = density of suspension, gm/cc

ρ water = density of water, gm/cc

$$\rho \text{ solid} = \frac{\rho \text{ water}}{1 - (\Delta W/\text{S.S.})}$$

Replicate densities of dry solids were done and the computed values averaged out. The error was estimated to be less than 3%.

Aggregate Density:

Samples from the column were collected in polyethylene bottles. The samples were gently mixed and allowed to stand until the residual turbulence disappeared and the sludge reflocculated. Sludge from the sample bottle was pipetted out using disposable pipets and placed over a dextrose solution of known density and temperature. The density solutions were prepared by dissolving known amounts of reagent grade dextrose and the exact density these solutions was determined with calibrated density bottles. The density of the aggregates was that of the density solution in which the sample remained in suspension for a few seconds. If the sample floated or sank, another sample was used and the procedure repeated. The method is based on the assumption that in the time allowed for the sample to remain in suspension, little or no mass transfer of solution would occur through the sample and that when the sample was placed in the density solution, water surrounding the aggregate dispersed in the upper layers of the medium. The sludge samples drawn from the column were assumed to be as representative of the sludge in the column, as the sludge in the column was representative of the sludge in the aeration tank.

The density solutions were prepared in increments of 0.0005 gm/cc, approximately. The errors in density determination is estimated not to exceed ±0.0003 gm/cc.

All settling tests were done without stirrers.

Results and Discussion:

Figure 1 depicts a typical height-time relationship characterized by:

1. A slight lag phase during which the sludge reflocculated and the residual turbulence subsided.

2. A zone of constant settling rate corresponding to a zone of constant solids concentration at the interface and constant aggregate density (Figures 2 and 3).

3. A zone of rapidly changing settling velocity corresponding to a zone of slowly changing solids concentration and aggregate density, and

4. A zone of slowly changing velocity during which both the solids concentration and densities of aggregates changed rapidly.

It is interesting to note from Figures 2 and 3, that both solids concentration and aggregate densities follow the same pattern. Furthermore, it should be noted that both solids concentration and aggregate densities showed an increase almost simultaneously. In all cases, aggregate densities remained constant although the solids concentration increased slightly. The fact that aggregate densities increased with concentration indicated that the aggregates were squeezed and that water was being removed from within the aggregates. This also indicated that as settling occurred, the size of the aggregates decreased.

Figure 4 depicts the relationship between aggregate densities and solids concentration. It is clear from the data that there are three zones:

a. An initial zone over which the aggregate densities are independent of concentration,

b. A non linear region followed by a flattening of the curve at approximately 6,000 mg/l, and

c. A linear relationship between density and concentration.

The concentration at the plateau corresponds to the compression point. Thus beyond the plateau, aggregates enter the compression stage. It can be said, hence, that the extent to which water is removed from within the aggregates depends on the structural strength of the aggregates and the weight of solids in suspension. Furthermore, consideration of equation 3 given in the experimental procedures, reveals that solids concentration is a function of the dry solids densities and the density of the suspension, and is thus, a function of the physical properties of the suspension. In this run, the dry solid density was determined to be 1.2 gm/cc. In general, the density varied from 1.2 to 1.85 gm/cc and this variation is attributed

to the amount of grit present in the flocs.

Figures 5 and 6 indicate the relationship between settling velocity, solids concentration and aggregate density. It should be noted that both curves appear to have the same shape and when superimposed, the curves seem to be parallel. The implications of these findings raise the questions as to whether or not settling rates are solely a function of solids concentration and whether or not the structure of the aggregates in suspension plays a significant role in sludge settling, and thus, in the determination of unit areas in clarifiers design.

At this point, the method of Eckenfelder and Ford, outlined earlier, appear to be best suited as it takes account of both factors. However, the use of one litre graduated cylinders may offer serious difficulties as discussed by Dick (1972). In the method of dilution there is no guarantee, as supernatant is added and the mixture mixed, that the sludge will recover its original structure and water content. Furthermore, there is no indication that at the various initial solids levels thus achieved, the sludge is representative of that grown in an aeration tank. Similarly, although in the single batch test the solids pass through the entire range of concentrations that could be anticipated, the settling velocity at each of these solids levels bears no relationship to the settling velocities observed for sludge from the same aeration tank at the same solids levels. A further evidence, that settling rates are not only a function of solids concentration, but also of the structural properties of the sludge itself.

Concluding Remarks:

A method of obtaining dry solids and aggregate densities has been presented. An evaluation of the various methods employed for the determination of clarifiers areas was made in the light of experimental evidence.

Acknowledgements:

Mr. Ray Stickney is gratefully thanked for his assistance and diligent laboratory work.

References:

1. Eckenfelder, W.W., Ford, D.L., "Water Pollution Control", Jenkins Book Publishing Co., New York, (1970).
2. Talmage, W.P., Fitch, E.B., "Determining Thickener Unit Area", Industrial and Engineering Chemistry, 47, (1955).
3. Coe, H.S., Clevenger, G.H., "Methods for Determining the Capacities of Slime - Settling Tanks", American Institute of Mining, Metalurgical and Petroleum Engineers, Transactions, 55, (1916).
4. Rich, G.L., "Unit Operations of Sanitary Engineering", John Wiley and Sons, New York, (1971).
5. Dick, I.R., "Gravity Thickening of Waste Sludges", Filtration and Separation, March/April, (1972).
6. A.P.H.A., "Standard Methods for the Examination of Water and Wastewater", 13th Edition, (1971).

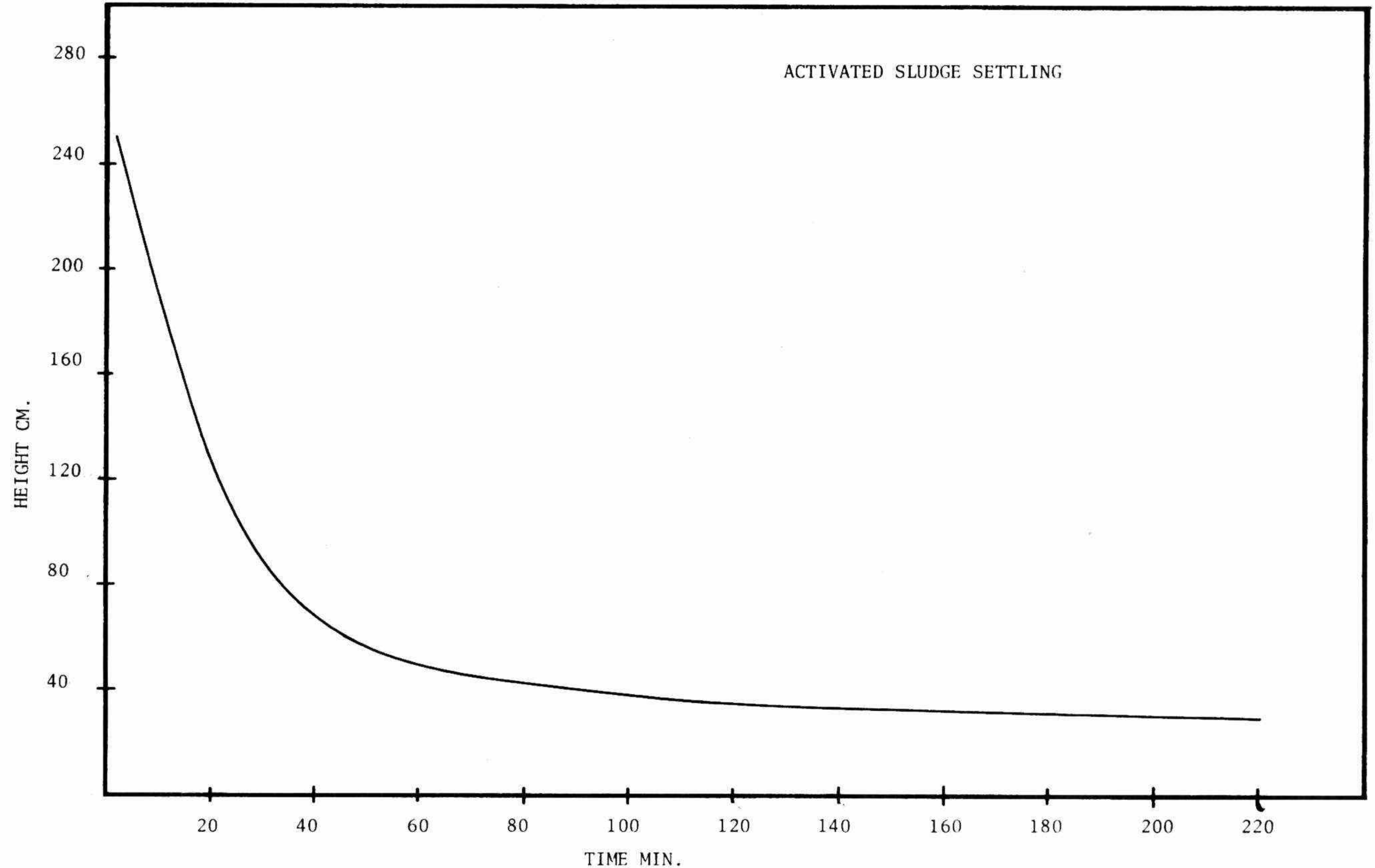


FIGURE 1 HEIGHT VS. TIME

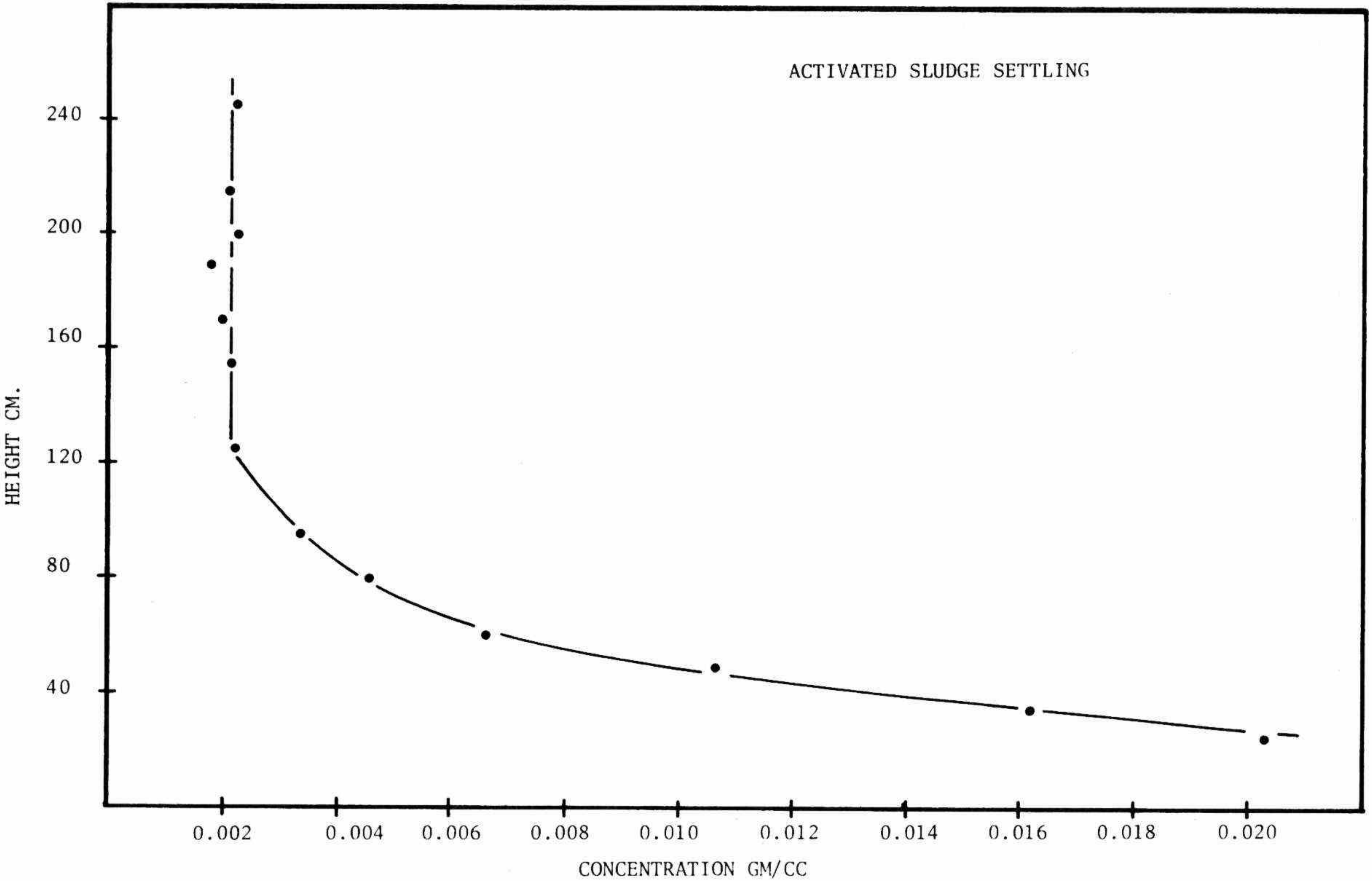


FIGURE 2 HEIGHT VS. CONCENTRATION

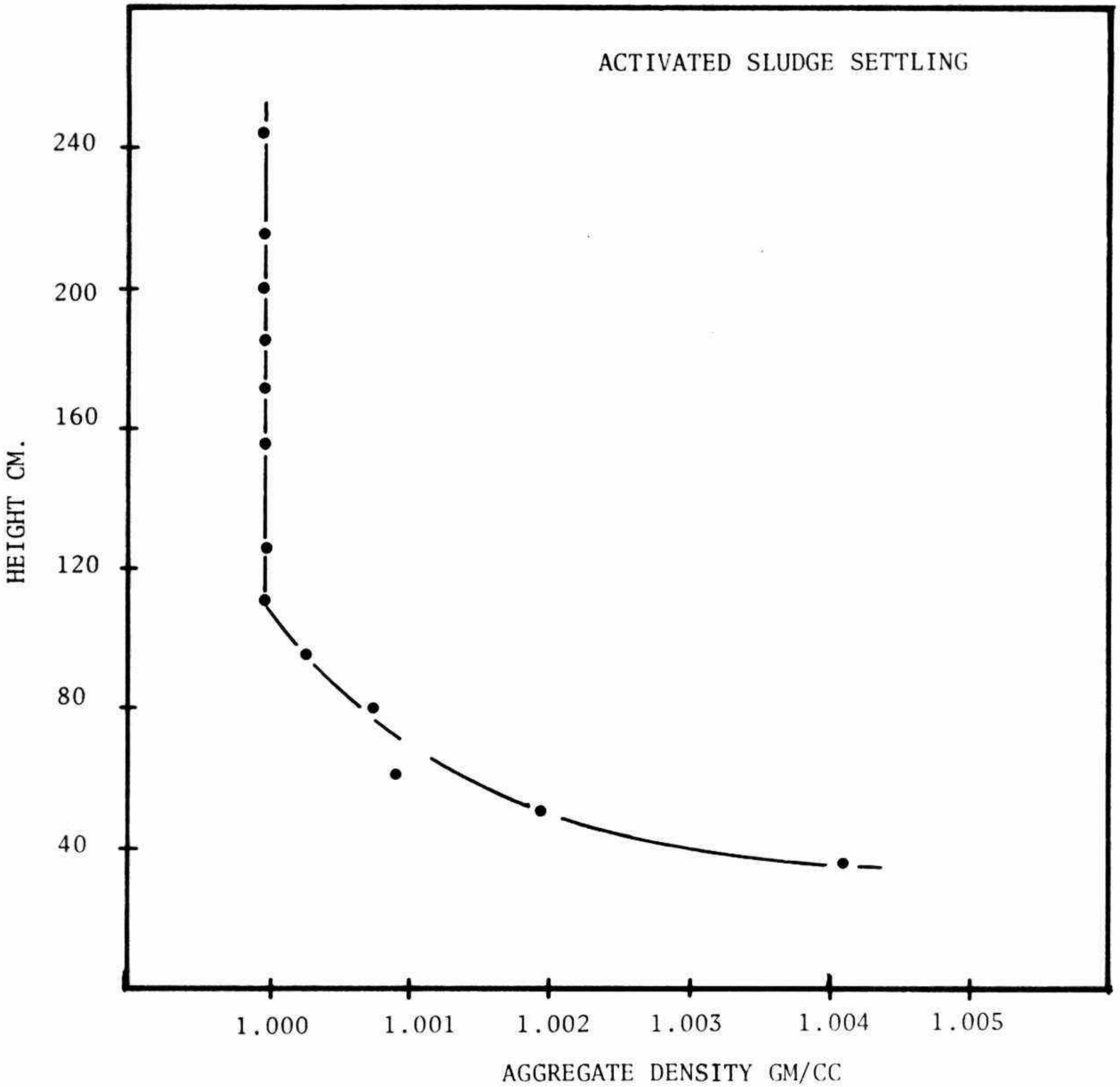


FIGURE 3 HEIGHT VS. AGGREGATE DENSITY

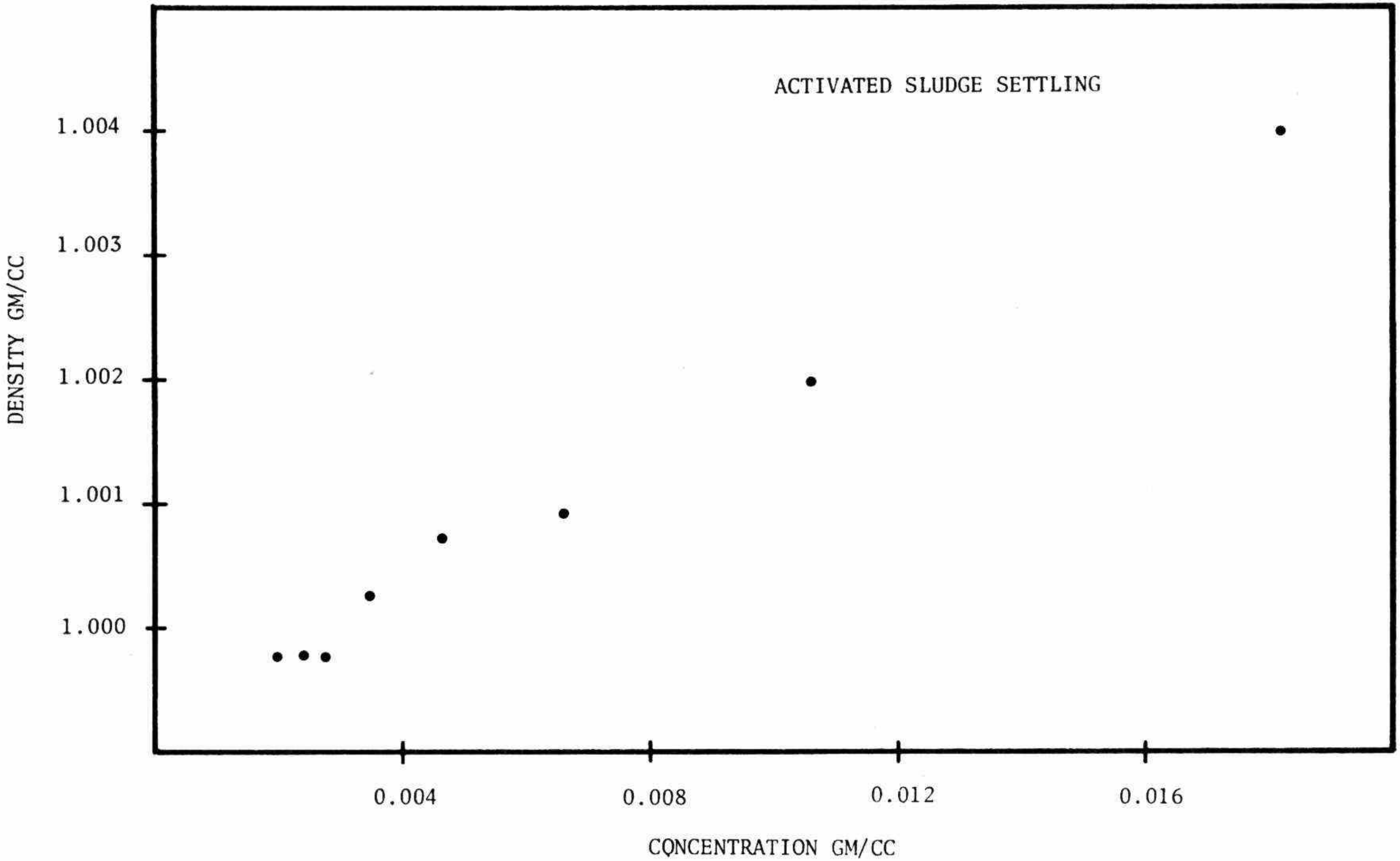


FIGURE 4 AGGREGATE DENSITY VS. CONCENTRATION

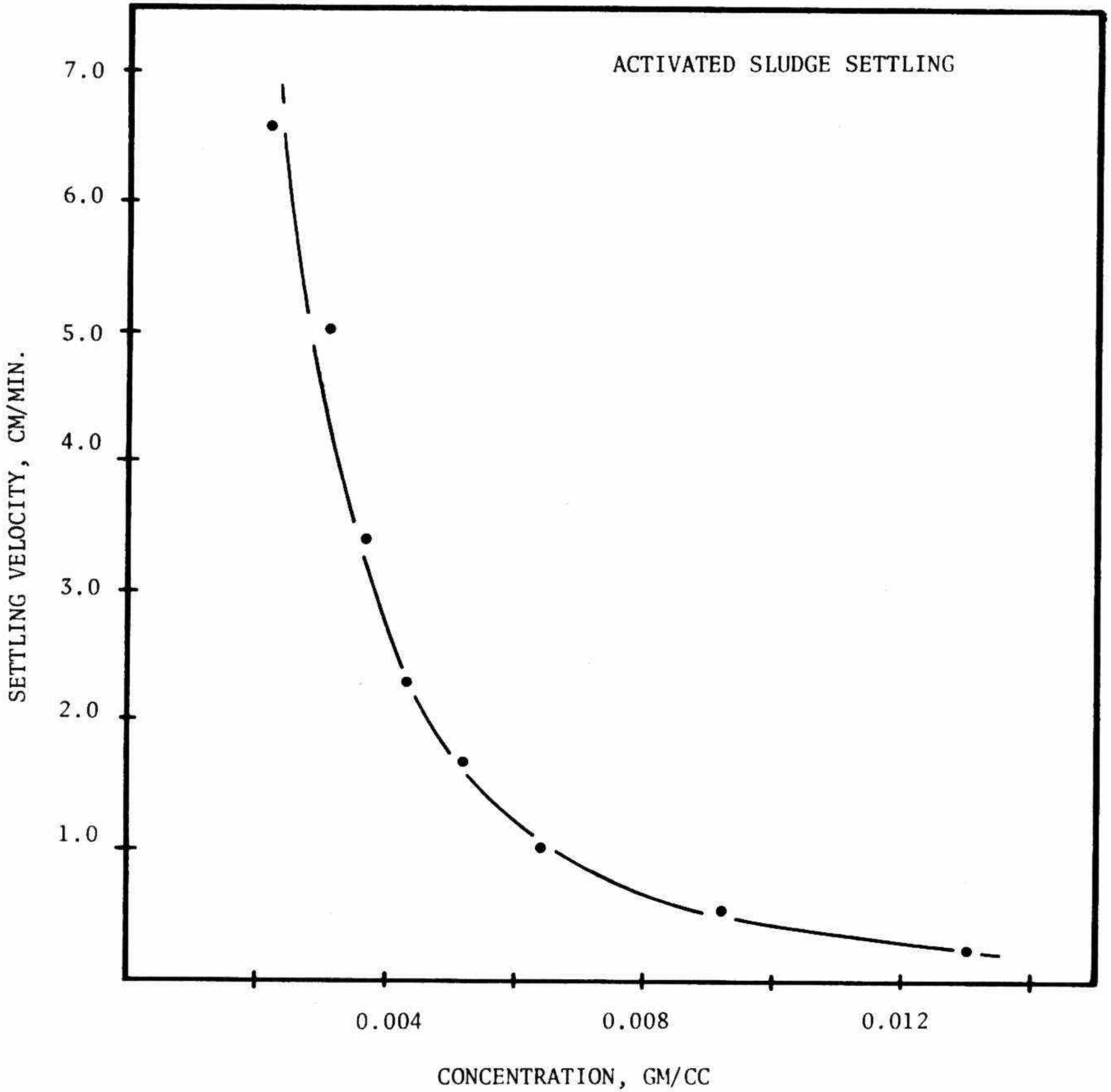


FIGURE 5 SETTLING VELOCITY VS. CONCENTRATION

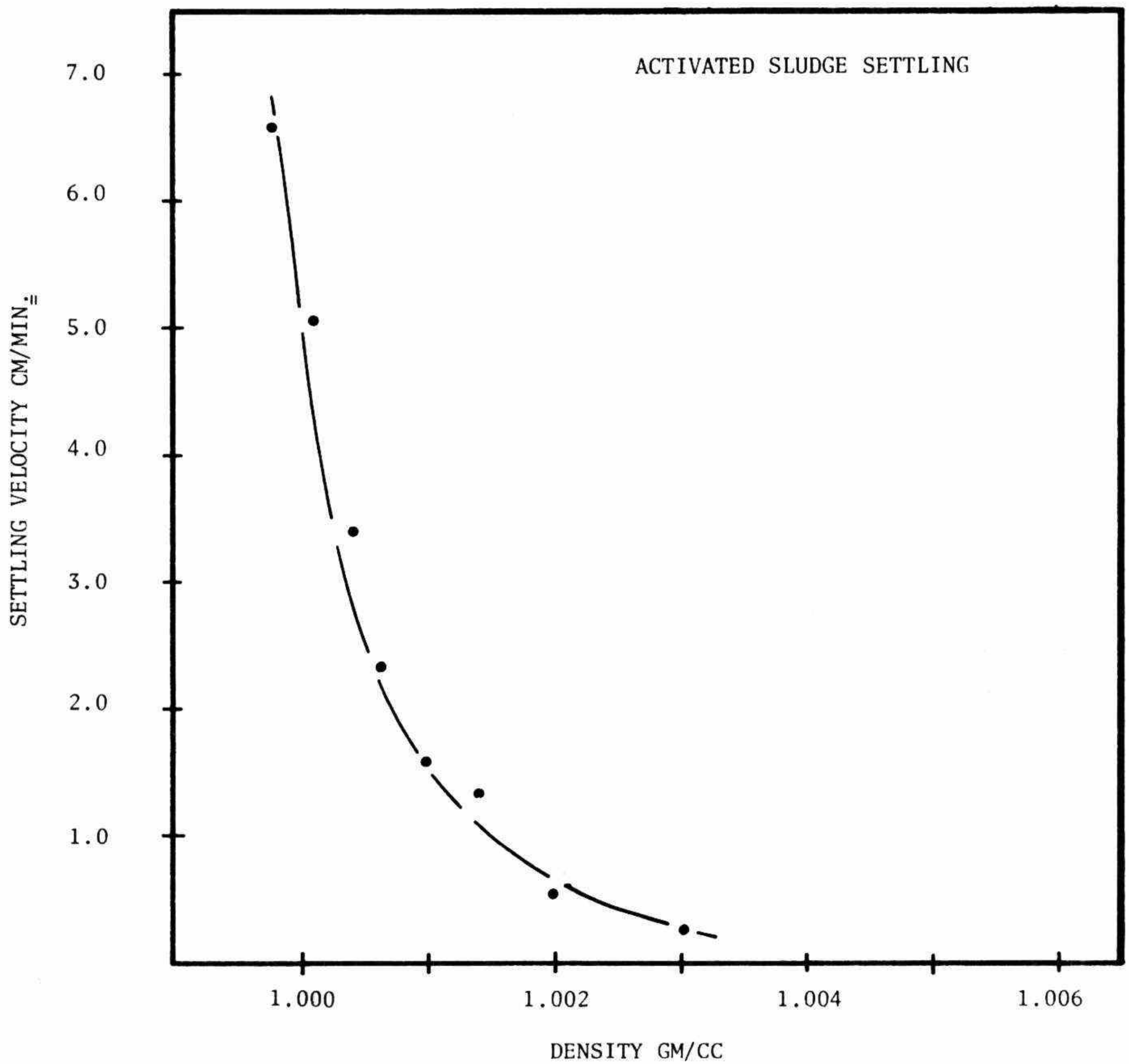


FIGURE 6 SETTLING VELOCITY VS. AGGREGATE DENSITY

THICKENING and DEWATERING SLUDGES

PRODUCED IN PHOSPHATE REMOVAL

by

C. H. Knight — Canadian EVT Limited
R. G. Mondoux — Eimco Envirotech Division
B. Hambley — Eimco Envirotech Division

TABLE OF CONTENTS

THICKENING AND DEWATERING SLUDGES PRODUCED IN PHOSPHATE REMOVAL

Ontario requires that municipal waste water treatment plants install facilities designed to remove 80 percent of the influent phosphorus. This is accomplished by precipitation with lime or certain salts of iron or aluminium which are usually added ahead of the primary clarifier or in separate treatment units following the secondary clarifier. The latter constitutes a form of tertiary treatment which is capable of removing not only over 90 percent of the phosphorus but also increases BOD and suspended solids removal. In the former, overall removals are not very different from standard biological treatment levels so that the weight of sludge solids captured due to suspended solids and BOD removal remains unchanged. Both processes produce chemical precipitates which are ultimately mixed with the sewage sludge solids captured and add to the dry weight of sludge solids for disposal. Addition ahead of the primary clarifier, however, greatly increases primary capture and hence decreases the proportion of biological sludge produced. The sedimentation and filtration characteristics of the sludges produced differ greatly from standard sludges. The prime design concern of dewatering processes is the wet weight or volume of dewatered product since this determines the size and cost of subsequent processing steps. The second main concern, of course, is capacity which governs the size and cost of the dewatering step.

Since most phosphate removal installations will be additions to existing Ontario treatment plants, this paper essentially attempts to compare the effect of adding 80 percent phosphate removal facilities on the capacity and efficiency of dewatering processes. Material and water

balances and average capacity figures are developed for the various dewatering processes and different chemical additions. It should be stressed that no two sludges are alike and it is desirable to conduct at least bench scale and preferably plant scale tests to confirm critical design conditions.

DRY WEIGHT OF DIFFERENT SEWAGE SOLID SLUDGES

FLOW 5.0 mgd U.S.

BOD 200 mg/I

SS 250 mg/I

TOTAL WEIGHT SS PER DAY 10412 lb

		STANDARD ACTIVATED SLUDGE	ACTIVATED SLUDGE PLUS CHEMICAL	TERTIARY PHOSPHATE REMOVAL
Pri. Removal	SS	50%	75%	50%
" "	BOD	35	50	35
Sec. Removal	SS	90	90	90
" "	BOD	90	90	90
Tertiary Removal	SS	-	-	95
" "	BOD	-	-	95
Primary Sludge	lb/day	5206	7809	5206
Sec. Sluuge	" "	4165	1562	4165
Tertiary Sludge"	"	-	-	521
Total Sludge	lb/day	9371	9371	9892

The above daily weights of dry sewage solids are derived simply by multiplying percentage removals by total weight of suspended solids in the influent. They do not allow for the organics consumed by endogenous respiration or for the soluble BOD converted during aeration into secondary sludge solids. For typical domestic sewage of the analysis shown, there is little difference in the weights calculated from either method. However with, say, a high BOD, low suspended solids sewage it would be desirable to use the more detailed calculation.

DRY WEIGHT OF DIFFERENT CHEMICAL PRECIPITATES

Lime

Phosphorus is precipitated as hydroxyapatite with the approximate formula $Ca_5(OH)(PO_4)_3$. Assuming 80 percent removal and 10 mg/l P in the influent, the dry weight of this precipitate from a 5.0 mgd plant is 1797 lb/day.

The percentage of phosphorus removed is essentially a function of pH with substantial removal occurring as low as pH 9.0. Better than 90 percent removal can be obtained at pH 11.0. The pH required to obtain 80 percent removal of phosphorus is below that at which substantial precipitation of $Mg(OH)_2$ commences. This has important effect on the thickening and dewatering characteristics of the sludge since magnesium hydroxide is bulky and dewaters slowly to a very low consistency.

The lime dosage needed to attain any desired pH level depends on the waste water alkalinity, hardness and relative quantities of calcium and magnesium. Fig. 1 illustrates the relationship between lime dosage and alkalinity at pH 11.0. The bulk of this lime reports to the chemical sludge as calcium carbonate which in turn constitutes the main constituent of the chemical sludge. One sludge analyzed from a weak, high alkalinity waste at Salt Lake City had the following analysis:

Sewage Solids	10%
$CaCO_3$	60
$Mg(OH)_2 + Ca_sOH(PO_4)_4$	10
Other calcium ppt	8
Unaccounted chemical solids	12

It is not possible to calculate accurately how much precipitate will report per pound of lime added. If all the lime added came down as $CaCO_3$, one pound of $Ca(OH)_2$ would yield 1.35 pounds of precipitate. If all the lime added were consumed in precipitating $Ca(HCO_3)_2$, one pound of $Ca(OH)_2$ would produce 2.70 pounds of $CaCO_3$ precipitate. If used up in

magnesia precipitation, one pound added would produce 1.35 pounds of $CaCO_3$ plus .39 pounds of $Mg(OH)_2$ for a total of 1.74 pounds of precipitate. One pound precipitated as hydroxyapatite produces 1.36 pounds of sludge.

Figure 2 illustrates the relationship between chemical sludge produced per pound $Ca(OH)_2$ added on the previously mentioned Salt Lake waste water. At Waterford N.Y., waste water with alkalinity 150 required a lime dosage of 125 mg/l $Ca(OH)_2$ to pH 10.0 and 240 mg/l to pH 11.5. At Windsor's Little River Plant, 125 mg/l raised the pH to 8.9 and 150 mg/l to pH 9.3. At Rochester N.Y., 130 mg/l raised the waste water to pH 9.5.

Assuming that the moderate alkalinity waste waters typical of municipalities drawing their water supply from the Great Lakes require 125 mg/l of $Ca(OH)_2$ to increase pH to 9.5 and that this produces chemical sludge at the rate of 2.0 lb per pound $Ca(OH)_2$ added, the chemical sludge for the 5.0 mgd plant we are considering will be 10412 lb/day - roughly equal to the sewage solids sludge produced. It is important in designing for lime addition to determine lime addition and sludge production by jar tests.

Alum

Phosphorus is precipitated by aluminium ions to form aluminium phosphate ($Al\ PO_4$). The aluminium is usually added as alum - $Al_2(SO_4)_3.14\ H_2O$. An excess of about 60 percent over stoichiometric ratio of aluminium to phosphorus is necessary because alum neutralizes alkalinity to lower pH. The excess aluminium is precipitated essentially as $Al(OH)_3$.

Thus in removing 8 mg/l of phosphate, the alum added will produce 1310 pounds of aluminium phosphate sludge and 500 pounds of aluminium hydroxide for a total chemical sludge of 1810 pounds.

Iron

Phosphorus is precipitated by ferric ions to form $FePO_4$. The reaction is very similar to aluminium precipitation and similar excess over stoichiometric Fe/P ratio is used. The excess iron reports as ferric hydroxide $Fe(OH)_3$ which is quite insoluble, flocculent and settles and filters reasonably well. Ferrous iron may also be used and, although the Fe/P mole ratio of the resultant phosphate $Fe_3(PO_4)_2$ is 1.5 instead of 1.0, the iron dosage required, for some reason, is not much greater than with ferric iron. However, ferrous hydroxide has appreciable solubility, settles poorly and is very slow filtering. In removing 8 mg/l of phosphate, ferric chloride added in 60 percent excess will produce 1622 pounds of ferric phosphate and 690 pounds of ferric hydroxide for a total chemical sludge of 2312 pounds.

COMPOSITION OF PHOSPHATE REMOVAL SLUDGES

Adding together the weights calculated for sewage and chemical solids gives the following comparison:

	Primary Sludge	Sec. Sludge	Tertiary Sludge	Chemical Sludge	Total Sludge
1. Standard Activated					
lb/day	5206	4165	-	-	9371
%	55.5	44.5	-	-	100
2. Activated Sludge					
Lime					
lb/day	7809	1562	-	10412	19783
%	39.5	7.9	-	52.6	100.0
Alum					
lb/day	7809	1562	-	1810	11181
%	69.8	14.0	-	16.2	100.0
Iron					
lb/day	7809	1562	-	2312	11683
%	66.8	13.4	-	19.8	100.0
3. Tertiary					
Lime					
lb/day	5206	4165	521	10412	20304
%	25.6	20.5	2.6	51.3	100.0
Alum					
lb/day	5206	4165	521	1810	11702
%	44.5	35.6	4.4	15.5	100.0
Iron					
lb/day	5206	4165	521	2312	12204
%	42.7	34.1	4.2	19.0	100.0

GRAVITY THICKENING OF PHOSPHATE REMOVAL SLUDGES

Thickened Consistency

The percent solids obtainable in the underflow from gravity thickening of sewage sludge solids varies widely depending on the volatile content and on the ratio of primary to biological sludge. Primary sludge underflows may range from 5 percent to 16 percent solids and activated sludge from 2 percent to 4 percent. Mixed primary and secondary sludges fall between these extremes and the Fig. 3 shows a typical relationship.

From this graph, the standard activated sludge we are considering containing 44.5 percent secondary sludge will thicken to 4.0 percent solids. Calculating the weight of wet sludge produced

Primary	5206 lb/day
Secondary	4165 lb/day
Total	9371 lb at 4.0% solids =

$$\frac{9371}{.04} = 234{,}275 \text{ lb/day.}$$

Addition of lime, alum or iron ahead of the primary clarifier increases primary removal so that only 16.7 percent of the sewage solids sludge appears as activated sludge. If there were no chemical precipitate present, such a mixed sludge would, from Fig. 3, settle to 6.0 percent solids.

The precipitate resulting from lime addition is predominantly calcium carbonate which settles very rapidly to as high as 30 percent solids. There is simply not enough data available to predict over the huge variety of sludges encountered whether the mixed sludge produced by chemical addition settles better or worse than a mixture of the components. It is assumed in the absence of such data that the mixed sludge will settle to the same volume which the two sludges would occupy if settled separately.

Thus, considering lime addition to the primary clarifier:

Sewage sludge = 7809 lb/day primary

1562 lb/day secondary

9371 lb/day total

At 6.0 percent, weight underflow = $\frac{9371}{.06}$ = 156200 lb/day

Chemical sludge = 10412 lb/day

At 30 percent solids, weight underflow = $\frac{10412}{.30}$ = 34707 lb/day

Total weight sludge 190907 lb/day

Overall percent solids in mixture = $\frac{9371 + 10412}{190,907}$ X 100

= 10.4%

The wet sludge so calculated for lime addition is only 81.5 percent of that from standard activated sludge.

In contrast to lime sludge, alum precipitate is akin to water treatment sludge which thickens very slowly to a maximum of 1.5 percent solids. Again assuming that the mixed sludge will settle to the same volume as the chemical precipitate and sewage sludge would occupy if settled separately, the calculated weight of thickened sludge produced from alum addition is 276,800 lb at 4.0 percent solids or 118 percent of that from standard activated sludge.

Ferric precipitate is somewhat denser than alum and will settle to approximately 3 percent solids. The calculated weight of thickened sludge works out to 213,983 lb at 5.5 percent solids or 91 percent of the weight of that from standard activated sludge.

Summarizing, the weight of various sludges produced is as follows:

	TOTAL SOLIDS		WET SLUDGE
	lb/day	%DS	lb/day
Standard Primary	5206	8	65075
Pri + Lime	18221	14	132318
" + Alum	9619	4.5	218279
" + Ferric	10121	5.5	184018
Std. Activated	9371	4.0	234275
Mixed + Lime	19783	10	197830
" + Alum	11181	4.0	279525
" + Ferric	11683	5.5	212418

From this, the weight of thickened wet sludge is increased two or three times when chemical is added to an existing primary plant. This, of course, would reduce the residence time in existing digesters by half to two thirds and they would not function unless initially away below design loading.

In contrast, chemicals added to an existing secondary treatment plant do not greatly change the weight of wet sludge to digestion so performance would be unchanged.

Gravity Thickener Capacity

Commonly used capacity figures for gravity thickening are shown in the following table:

Sludge Type	Loading psf/day
Primary	22
Primary and Waste Activated	10
Waste Activated	4
Physical Chemical Sludges	
(no excess activated)	
Lime	30
Alum	5
Ferric Chloride	10

Again, little data is available for sludges produced by chemical addition ahead of the primary or for tertiary addition. Prudent design should probably call for at least using the weight of chemical plus primary sludge divided by

the loading for the chemical sludge used plus the weight of activated divided by the activated loading. For example, considering lime addition:

Wt. primary sewage sludge	7809 lb/day	
Wt. chemical sludge	10412 lb/day	
Total	18221	
Thickener area required	$\frac{18221}{30}$ = 607 sq ft.	
Wt. activated sludge	1562 lb/day	
Thickener area required	$\frac{1562}{4}$ = 390 sq ft	
Total area required		997 sq ft
Thickener diameter		36 ft

Similar calculations for the other additives produce the following comparison:

Sludge Type	Thickener Area (sq ft)	Diameter (ft)
Primary and Waste Act.	937	36
Lime Addition	997	36
Alum Addition	2264	50
Ferric Addition	1327	45

Polymers are effective in increasing solids loading rates beyond those shown but except in uneconomically large dosage, do not increase underflow consistency. In existing plants where samples are available, standard Kynch or Coe-Clevenger settling tests should be used to determine thickener size and expected underflow consistency.

FLOTATION THICKENING

Since the quantity of waste activated sludge is reduced by 62 percent when chemical is added ahead of the primary clarifier, separate flotation thickening of waste activated sludge is less likely to be economical than with standard activated sludge or with tertiary phosphate removal.

Flotation has been used experimentally to separate alum sludge produced by addition following the primary clarifier and also in tertiary treatment. Phosphate removals are reported to

be good. In thickening activated sludge, normally the only chemicals are polymers but other chemicals that promote flocculation are unlikely to be harmful. Lime, alum and ferric chloride have all been used in treating such wastes as meat packing, laundry wastes, cannery wastes etc. It appears that flotation of waste activated sludge is likely to be equally efficient with phosphate removal as with standard activated sludge. The usual loading of 1.25 - 1.5 gpm/sq ft/hr and float at 3-4 percent solids should apply.

NOZZLE DISCHARGE DISC CENTRIFUGE THICKENING

These units have recently been applied to thicken waste activated sludge in competition to flotation methods. Separation takes place in a large number of narrow sedimentation chambers between stacked conical discs, much like a cream separator. The separated solids are further thickened and discharged continuously through small orifices in the bowl wall. Large units have reported to be capable of thickening up to 350 gpm to 5-6 percent solids at 80-95 percent removals without polymer. As with flotation, they should be at least equally efficient on excess activated sludge when phosphate removal is practised. However, it has been proven necessary to use hydroclones to protect against excessive abrasion on standard activated sludge. It is possible, particularly with lime precipitation, that the crystalline precipitates could cause increased abrasion.

VACUUM FILTRATION

Cake Moisture

SEWAGE SOLIDS VOLATILE 75%

VOLATILE REDUCTION IN DIGESTION 50%

CHEMICAL SOLIDS INCLUDE BOTH PHOSPHATE PRECIPITATING AND CONDITIONING CHEMICAL SLUDGES

SLUDGE	SEWAGE SOLIDS	CONDITIONING CHEMICAL		CHEMICAL SOLIDS	TOTAL SOLIDS	CAKE MOISTURE	WEIGHT WET CAKE
	lb/day	%$FeCl_3$	%CaO	lb/day	lb/day	%	lb/day
RAW PRI.-STD.	5206	1.5	7.0	703	5908	70	19693
" " -LIME	7809	-	-	10412	18221	55	40491
" " -ALUM	7809	Polymer or	15	1810	9619	80	48095
" " -FERRIC	7809	"	"	2312	10121	80	50605
DIG.PRI.-STD.	3228	4.0	12	776	4004	73	14830
" " -LIME	4880	-	-	10412	15292	55	33982
" " -ALUM	4880			1810	6690	80	33450
" " -FERRIC	4880			2312	7192	80	35960
RAW PRI. + ACT.							
-STD.	9371	2.5	10	1828	11199	78	50905
-LIME	9371	-	-	10412	19783	66	58185
-ALUM	9371			1810	11181	80	55905
-FERRIC	9371			2312	11683	80	58415
DIG.PRI. + ACT.							
-STD.	5857	5.5	19	1987	7844	79	37352
-LIME	5857	-	-	10412	16269	64	45191
-ALUM	5857			1810	7667	80	38335
-FERRIC	5857			2312	8169	80	40845

VACUUM FILTRATION

Capacity

OPERATING TIME 35/HR/WEEK

FEED SOLIDS INCLUDE PHOSPHATE PRECIPITATE SLUDGE

BUT NOT PRECIPITATES FROM CHEMICAL CONDITIONING

SLUDGE		SOLIDS IN FEED			RATE	AREA	SIZE	
		TOTAL	CHEMICAL	%			DIA.	LENGTH
		lb/day	%	DS	lb/hr/sq ft	sq ft	ft	ft
RAW. PRI.								
	-STD	5206	0	8	9.6	108	1-6	X 6
	-LIME	18221	57	14	12	303	1-10	X 10
	-ALUM	9619	19	4.5	2.2	887	2-10	X 14
DIG.PRI.								
	-STD	3228	0	6	5.2	124	1-6	X 8
	-LIME	15292	68	12	10	305	1-10	X 10
	-ALUM	6690	27	3.5	1.5	912	2-10	X 16
	-FERRIC	7192	32	4.5	2.2	650	1-12	X 18
RAW PRI. + ACT.								
	-STD	9371	0	4	3.5	535	1-10	X 18
	-LIME	19783	53	10	6	659	1-12	X 18
	-ALUM	11181	16	4	1.8	1259	2-12	X 18
	-FERRIC	11683	20	5.5	2.4	997	2-10	X 16
DIG.PRI. + ACT.								
	-STD	5857	0	4.5	3.5	334	1-8	X 14
	-LIME	16269	64	11	6	542	1-10	X 18
	-ALUM	7667	24	4.5	1.4	1059	2-12	X 14
	-FERRIC	8169	28	5	2.0	797	2-10	X 14

Where direct data is not available, some of the cake moistures shown in these tables are derived by interpolation, as in the case of the thickening tables, on the assumption that the water in the filtered cake will equal the sum of the water in the two cakes produced if the chemical sludge and sewage sludge were filtered separately. Similarly, some of the filter areas shown are interpolated on the assumption that

the area is the sum of the areas required to filter the chemical sludge and the sewage sludge separately. A somewhat similar relationship is known to hold for different mixtures of primary plus excess activated sludge as shown in Fig.4.

It will be seen that the addition of chemicals to an existing primary plant increases the required filter area by about three times for lime, eight times for alum and six times for ferric chloride. With activated sludge the increase in filter area is much smaller.

The use of anionic polyelectrolyte flocculation aid can produce significant increase in filter capacity. For example, dosage of .2 to .6 lb/100 lb dry solids of Dow Chemical AP-30 increased filter yields of physical chemical lime sludges of Salt Lake sewage from 30 to 70 percent above those with no polymer.

The squeegee is a type of vacuum filter operating at very low vacuum and featuring disposable or throw-away media such as paper or gauze. It would not appear to have any particular merit or disadvantage relative to drum filters when applied to phosphate sludges than to other sludges.

CONVEYOR TYPE CENTRIFUGE DEWATERING

For many years these units have been used as an alternative to vacuum filtration where low capture of solids was acceptable. They function best on relatively coarse sized sludges such as primary settling or heat treatment which contain little colloidal material and are not applied to straight activated sludge.

The development of long chain, high molecular weight polymers has greatly improved solids capture so that they are now applied to primary and mixed digested sludges and even to new mixed sludges at low ratios of activated to primary sludge. The consumption of polymer increases and the capture and cake moisture deteriorate as finer sludges are treated.

On primary raw sludge recovery is 70 to 80 percent without chemical and 95 percent with polymer. On digested mixed sludge without chemical, recovery is 60 to 70 percent and 95 percent with polymer.

Cake moistures are usually a few percentage points higher than from vacuum filtration. Typical polymer dosage ranges from 2 lb/ton for raw primary up to 10 lb/ton for mixed sludge.

When applied to lime phosphate sludges, these centrifuges should give excellent recovery of the chemical precipitate although wear would be increased due to the crystalline nature of the calcium carbonate. Recovery of the sewage solids will be similar to that from plants that do not practice phosphate removal.

When applied to alum or ferric sludges, the gelatinous nature of the chemical sludge is likely to decrease capture and increase cake moisture. Alum sludge cake contains 82 to 85 percent moisture. Recovery depends very much on the polymer dosage so increased consumption is probable when alum or ferric precipitation is added to an existing plant.

REFERENCES

Schepman, B.A., "Designing Vacuum Filter Systems to Fit the Type of Sludge." Wastes Engr., pp 162-165 (Apr. 1956)

Trubnick, E.H., "Vacuum Filtration of Raw Sludge." Water and Sewage Works Vol. 107, pp R287-R292 (1960)

"Process Design Manual for Phosphorus Removal" for U.S. Environmental Protection Agency Technology Transfer by Black and Veatch, Consulting Engineers, Oct. 1971.

Ministry of the Environment and The Pollution Control Association of Ontario, Proceedings of the Technical Seminar on Physical-Chemical Treatment,Mar. 9, 1972.

Ministry of the Environment and The Pollution Control Association of Ontario, Proceedings of the Technical Seminar on Sewage Sludges- Conditioning, Dewatering and Disposal, Nov. 16, 1972.

Tofflemire, T.J. and Hetling, L.J. "Treatment of a Combined Wastewater by the Low-Lime Process," Journal WPCF, Feb. 1973.

G.L. Shell, Eimco-Envirotech, Salt Lake City, Utah. Inter-office communication.

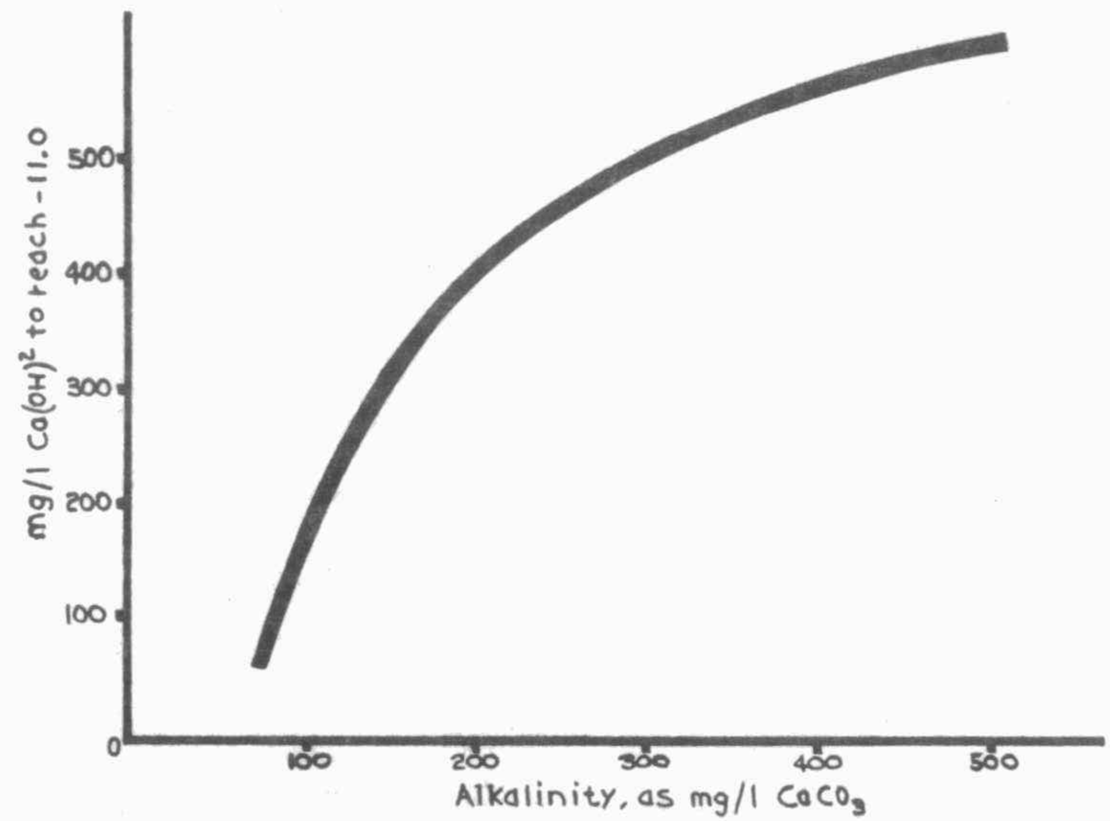


Figure 1 Relationship Between Lime Dosage And Alkalinity at pH 11 And Constant Hardness.

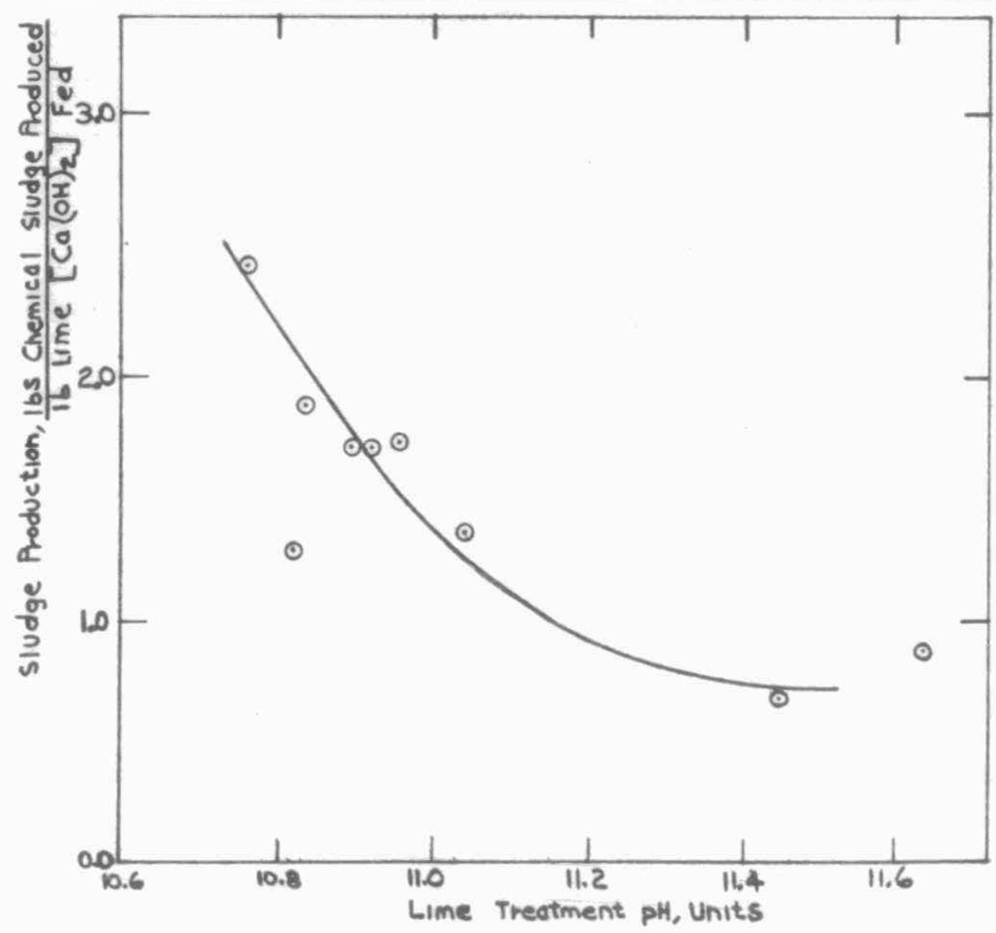


Figure 2 Lime Treatment : Sludge Production

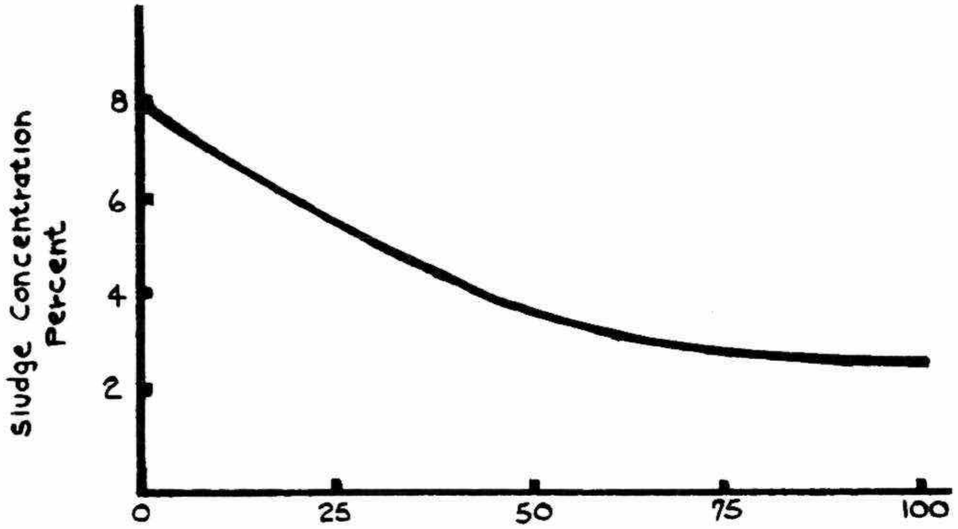


Figure 3 Percent Activated Sludge in Mixture

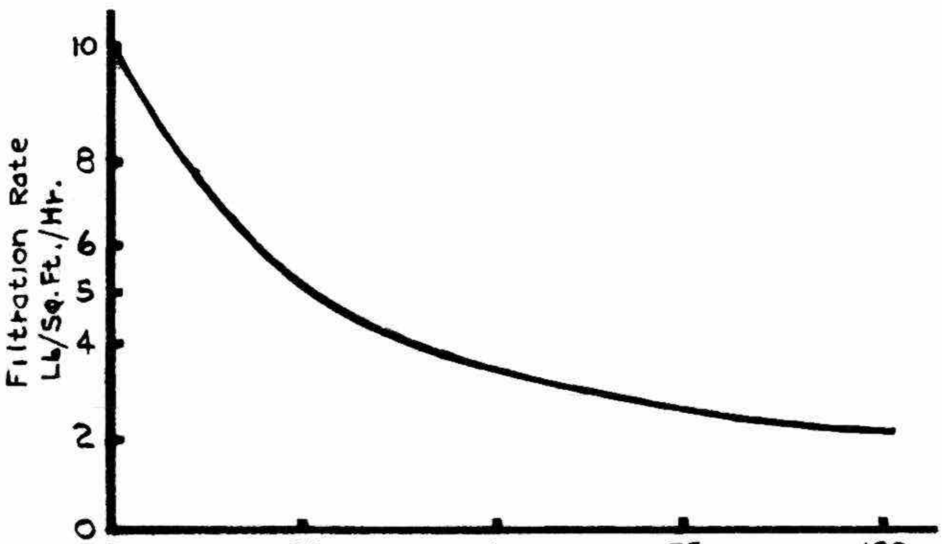


Figure 4 Percent Activated Sludge

A CURSORY LOOK AT THE IMPACT OF PHOSPHORUS LADEN SLUDGES ON CONVERSION PROCESSES

by R. V. Villiers

What are conversion processes?

Those processes which have as their goal the alteration of sludge constituents to make them inoffensive, nonviable, or unextractable to permit reuse or return of the sludge to the environment. A reduction in sludge volume and volatile content may or may not occur during the process.

Conversion processes include:

Physical processes

- Heat treatment - Zimpro, Porteous, Farrer, pasteurization
- Incineration - mutiple hearth, fluidized bed, rotary kiln

Biological processes

- Anaerobic digestion
- Aerobic digestion

Chemical processes

- Chlorination - Purifax
- Lime

Conversion processes have things in common.

All are temperature or pH dependent.

All are sensitive to change in loading, time, and mixing.

Some are sensitive to change in air and food supply.

All are concerned with organic matter destruction or stabilization.

To evaluate the impact of phosphorus sludges (P-sludge) on the conversion processes really involves two questions.

One, what is the effect of P-sludge on the conversion process, if any?

Two, what is the effect of the conversion process on the P-sludge?

Stratagem for answering the above questions.

First, identify the changes P-sludge produce in sludge characteristics. Then relate these changes to the operating or design parameters of the conversion process and predict the effect of the change on the process.

Second, identify the changes which occur in the sludge (or process) during conversion and predict the effect of the change on the P-sludge.

Therefore, need to identify:

(1) Changes in sludge characteristics,

> More volume (?)
> More weight
LESS > calorific value per lb (?) *
> Increase in volatile solids per lb (?) *
> Increase in moisture content (?) **
> Increase in inerts per lb

* Will depend on raw wastewater characteristics, chemical used, point of chemical addition, and clarifier performance, and type of plant.
** Will depend on prior processing.

(2) Process operating parameters,

> pH
> Temperature
> Loading
> Time
> Mixing
> Food
> Air

and (3) Changes the sludge components see during conversion,

> pH
> Phase changes
    Insoluble to soluble
    Volatiles to gases and ash
> Temperature

By relating the foregoing three categorizations to the various conversion processes effect-cause relationships between the process and the P-sludge can be predicted.

Incineration

Design parameters: Temperature, solids loading, air supply, volatile content of sludge, moisture content of sludge.

Effect of P-sludge: More solids loading, volatile and inert.
Less BTU'S per lb of sludge (?)
More moisture per lb of sludge (?)

which means - more supplemental heat, more ash to dispose of, an increase in operational time.

Possible Problems: See clinker problem.
Gas scrubbing, various oxides

Summary: With good furnace operation and maintenance, other than a slight increase in operational costs P-sludges should have no effect on incineration processes.*

Heat Treatment

Design parameters: Temperature, air supply, pressure, solids concentration.

Effect of P-sludge: More solids loading, volatile and inert.

which means - more air, more heat, less capacity, more ash to dispose of, more soluble organics in liquid.

Possible problems: Low pH of the process due to volatile acid production. Solubilization of P-forms.
If lime sludge, solubilization of $Mg(OH)_2$.

Summary: P-sludge will not effect heat treatment processes other than to decrease capacity and increase ash disposal problem. Liquid quality will decrease and this poses a potential deterent to the process.

*
With reservation that the sludge can be adequately dewatered prior to incineration. This is presently a concern.

Anaerobic Digestion

Design parameters: Solids volatile content, detention time, mixing, temperature, feed concentration, solids loading rate.

Effect of P-sludge: Less volatile solids per lb.
More inerts per lb.
Decrease detention times
Mixing (Lime sludge).

which means - more gas production, less digester capacity, more sludge to ultimately dispose of.

Possible problems: Low pH in digestor could solubilize P-forms and $Mg(OH)_2$. See Lake County, Ohio* and Contra Costa data. Some indications of poor liquid-solids separation. See note on US plants. Also German information on iron sludges.

Summary: Canadian experience certainly indicates that P-sludges should not materially unbalance performance of the process. American experience is hazy. More data and information required. Caution should be exercised in loading the process particularly with fresh lime sludge and P-sludges with significantly high volatile solids content.

Aerobic Digestion

Design parameters: Solids retention time, temperature, air requirements, aeration time, loading rate, mixing.

Effect of P-sludge: Increased loading, volatile and inert
Less detection time
Less capacity

which means - more air required, decrease in capacity, more sludge to dispose of ultimately.

Possible problems: Increased organic load may exceed air capacity. Lime sludges may impose additional mixing load.

Summary: P-sludge may increase process costs because of increased air requirements and addition sludge disposal but should have little effect on process performance.

* Really a classification phenomenon here rather than solubilization.

Other Processes

Pasteurization - heat with steam to 75°C for 1 hour.

Lime stabilization - raise pH to 11-11.5 with lime.

Chlorination - dose sludge with 2000 mg/l Cl_2.

Effect of P-sludge: More volume.
Less capacity because of inerts.

which means - more stabilizing agent required,
increased operational time,
better mixing

Possible problems: None other than possibly poor dispersion of stabilizing agent due to inerts.

Summary: Providing adequate mixing is present, P-sludge should have no effect on the above processes other than slight increase in cost for the increase in stabilization agent requirements.

MISCELLANEOUS NOTES

Incineration

Feed solids requirements: Rotary kilns, 7-70%
Stationary incinerators, 25-70%
Fluidized beds, 2-10%
(also wet oxidation)

Heat balance, a major concern -
> minimize the amount of heat required by reducing moisture (solids greater than 30% needed)
> maximize the fuel value of the solids

In many instances, chemical addition will work against the above -
> Fe and Al sludges contain more moisture, costly to dewater
> Chemical will dilute sludge with inerts, decreasing its BTU/lb value
> Heat available will be reduced due to heat used up in the dehydration of hydrous sludges
> Consideration must be given to inorganics present that that react endothermically as heat sinks,
$CaCO_3$ to CaO

Consider blending organics with chemical sludges, perhaps solid wastes or industrial wastes.

Temperature, a key parameter -
> Multiple hearth, 1400-1800°F
probably localized hot zones in excess of hearth temp.
> Fluidized bed, 1200-1500°F
homogenous bed conditions minimize hot zones

Important sludge parameters: moisture, volatiles, inerts, calorific value.

Some chemical reactions:

$Al(OH)_3$ less H_2O	572°F
$Mg(OH)_2$ less H_2O	662°F
$Fe(OH)_3$ less H_2O	932°F
$AlPO_4$	2732°F
Various oxides	>2800°F

Mutiple hearth ash analysis: SiO_2-66%, Al_2O_3-15%, CaO-8%, $FeO+MgO+NaO$-9%.

THE " CLINKER " PROBLEM (?)

(a) Mutiple hearth incineration of iron sludge - Ann Harbor.

Observed clinkers at furnace temperature of 1150°f.
Iron dosage 60 mg/l.

Changing from Fe to Al.

(b) Fluidized bed incineration of iron sludge - Long Island, NY.

10-20 mg/l Fe to primary.

Granular agglomerates formed. Analysis, $Ca \cdot PO_4$, SiO_2, Fe_2O_3

Temperature about 1700-1800°F in area adjacent to clinkers, possibly 2000°F in area where they were formed.

$Fe_4(P_2O_7)_3$ + $CaCO_3$ goes to $Ca \cdot PO_4$ + Fe_2O_3

(c) Indication iron sludge clinkers occur at furnace temperatures above 1600°F. (David Nakles, Dow Chemical Co.)

(d) Laboratory, limited tests, muffle furnace. Clinkers formed at iron dosage of raw of 90 mg/l and furnace temperature of 1200°F.

Heat Treatment

Complete oxidation of organics at 400-650°f and 1200-1800 psig. 90% at 500°F and 1200 psig.

Economical operation at Chicago required 4000 BTU/gallon of sludge (about 6% acitivated sludge solids).

Significant concentrations of nutrients and soluble organic material contained in the liquid phase. Liquid high in ammonia and volatile acids. pH in the range 5 to 6.

Ash disposal required. Gases possible pollution source.

Insoluble organic matter to soluble organic matter which is oxidized to CO_2 and water. Org-N to NH_3. S to SO_4.

(a) Porteous process, Lake County, Mentor Plant, Ohio.

Pickle liquor to raw, 36 mg/l Fe^{++} , pH adjusted to 7.5-8.0 with lime (1.5 g/g Fe)

375°F for about 45 minutes. Pressure-?

Pressure filters sludge. Filtrate high in color and solids. Changing to tighter cloth.

No scale build-up noted. Operational only 30 days. Little information available.

(b) Zimpro process, Midland, Michigan.

Iron to raw. Substantial improvement in filterability even when there is a substantial loading of $Fe(OH)_3$ and $FePO_4$. No other information.

(c) Zimpro process, Columbus, Ohio.

No phosphorus removal being practiced. Observation that only 6 mg/l P found in liquor whereas the sludge contains 20-30 mg/l P.

Anaerobic Digestion

Canadian experience most comprehensive.

> Iron to raw, North Toronto - initial problems with dosing digester, loss of gas but with adjustments satisfactory performance.

> Alum to raw, Barrie, slight release of soluble P.

> Lime to raw, New Market, slight decrease in gas production.

United States experience somewhat limited.

> Iron to raw, Lake County, Ohio. Reports normal gas and pH. Digester supernatant quality a big if and question. See below.

	Primary Sludge Analysis Raw (mg/l)	Digested (mg/l)	Digester Supernatant (mg/l)
Total iron	3750	1020	3950
Soluble iron	105	26	trace
Total P	1140	393	1240
Soluble P	82	33	7

> Iron plus lime to raw, Lake Odessa, Michigan. Reports that P release was not occuring during digestion. Large volumes of sludge shortened digestor residence time but stabilization did occur.

> University of Missouri, Rolla. Alum to high rate activated sludge. 70% activated sludge and 30% primary to digester. P and Al concentrated in sludge. Digester performance versus control equivalent.

> Alum to high rate acitivated sludge, Manassas, Va. No resolublization of P during anaerobic digestion.

German experience, Kehr and Mohle, Stadtehygiene, Sept. 1966. Reports findings that P in iron sludges solublizes during anaerobic digestion and recommends aerobic digestion of this type sludge

Other American experience:
Alum to raw - Richarson, Texas - Chapel Hill, NC, Sandusky
All report poor solids separation in digester.

Anaerobic Digestion-Centrate from the centrifugation of lime sludge.
Central Contra Costra, California

Lime to raw wastewater.
Pilot scale study of processing centrate from centrifugation of lime sludge by disposal to anaerobic digester.
Feed solids to digester, 2.5% up to 7.1%.
Results show that

> all of the $Mg(OH)_2$ is solubilized (pH 7-8)
> $CaCO_3$ and P-forms not dissolved to any significant degree.

Other observations:

Control had better volatile matter reduction, lower methane content (CO_2 absorbed by lime in test unit), about the same methanr production per lb VSS (but VSS loading was greater in the control. Because of the low pH, a slight amount of soluble ortho-P is released. No evidence of calcium deposits or corrosion.

Aerobic Digestion

Used extensively in Penn.

If clarified, supernatant low in organics and nutrients. Liquid sludge to land disposal.

Use of oxygen instead of air improves total solids removal by 50% and results in complete nitrification.

Because operation of the digesters requires the periodic removal of supernatant, mixing requirements for digesters must include the capability of resuspending settled solids that accumulate during the settling period. Solids deposition dependent on - method of operating digester, tank configuration, location of air diffusers, solids concentration in digester, and type of feed sludge. (from Ahlberg & Boyko).

Sludge Handling

The use of iron and lime adds to the weight and volume of sludge, most of which is due to phosphate removal and higher suspended solids removals. The remaining portion consists of calcium carbonate and iron hydroxide. There was no significant influence of the use of ferrous chloride and lime on routine plant operation throughout the program other than this additional weight and volume of sludge, with a corresponding increase on the load in the digestion process and sludge handling equipment.

Variations in plant load and in the mode of digester operation did not permit a long-term study of sludge handling requirements during this program. The recirculation of suspended solids to the primary settlers from the digester supernatant also interfered with the determination of solids balances, a condition which prevailed at Mentor even prior to the start of ferrous iron and lime addition.

Raw Sludge Production

The quantity of sludge removed at Mentor varied widely from day to day, depending mainly on one or a combination of three factors:

1. Composition of the sludge, including the proportion of chemical additives.
2. Characteristics of the digester supernatant and frequency of return.
3. Hydraulic overloading, with consequent inconsistencies in the quantity of sludge removed during the period of overloading.

Short term tests indicated that in no case was the volume of sludge produced by treatment with ferrous chloride and lime more than double that produced by primary treatment without chemicals. Part of the increase was due to increased solids return from the overloaded digester.

Sludge Digestion

The No. 1 digester was designed for a minimum of 28 days digestion at 98° F. Prior to the iron-lime phosphate removal test period the digester residence time was a minimum of 36 days while during the test period residence time ranged from 8 to 14 days. The decrease in digestion time arose from three major factors:

1. Increase in plant wastewater flow rate from an average of 2.39 MGD in 1968 to 4.36 MGD in 1970.
2. Increased suspended solids removal and the formation of inorganic iron phosphate along with other iron, calcium, and magnesium precipitates from the iron-lime treatment.
3. The creation of a primary settler-digester recycle load of up to 100 percent due to poor No. 2 digester settling. This was caused by the short digestion time and by a low digestion temperature due to heat exchanger overloading.

Although digester residence time was shortened, stabilization did occur and the superior dewatering characteristics of the iron-lime sludge aided in its efficient disposal. Further, a decrease in both total and soluble phosphorus concentrations in the digester supernatant liquor was observed during and immediately following the periods of chemical treatment. The volatile solids of the digested sludge averaged 41.9 percent during a typical test with iron and lime. Some deterioration in sludge digestion was observed during treatment with ferrous chloride and lime when accompanied by low digester temperatures as determined by a decrease in gas production. Sludge was examined on several occasions and only trace amounts of soluble iron and phosphorus were found, although large amounts of insoluble iron and phosphorus were recirculating in the digester supernatant as shown in Table XIII.

TABLE XIII

Typical Iron and Phosphorus Analyses During Sludge Handling

Note: all quantities expressed in mg/l	Primary Sludge Analysis Raw	Primary Sludge Analysis Digested	Digester Supernatant
Total Iron	3750.0	1020.0	3950.0
Soluble Iron	105.0	26.0	trace
Total Phosphorus (as P)	1140.0	393.0	1240.0
Soluble Phosphorus	81.5	32.7	6.6

Gas Production

Treatment of sewage with ferrous chloride and lime was not observed to inhibit the bacterial destruction of organic solids by the formation of methane and carbon dioxide in the digesters. However, gas production did decrease as temperature in the heated digester decreased, a condition typically observed with high solids influents, hydraulic overloading and cold weather operation.

Supernatant Return

The return of digester supernatant liquor to the plant process adversely affected the overall removal of phosphorus. The suspended solids in the supernatant return averaged approximately 13,900 pounds per day during a typical test, ranging from approximately 2,200 to 14,800 pounds per day, at concentrations of between 0.5 and 8.5 percent. Less than 15 percent of the returns contained fewer than 1.0 percent solids, and the average was 4.0 percent.

The settling properties of the high solids supernatants were extremely poor, which can be attributed to the reduced residence time and temperature in the heated digester. On many days the sludge that was withdrawn for filtering contained less than five percent more solids than the supernatant itself. Laboratory cylinder tests indicated no continued settling over a twenty-four hour period. However, adequate settling was observed when the sludge was diluted with an equal volume of water. Additions of polymer were ineffective.

All factors indicated that a simple digester system overload existed that could be corrected by the addition of digester volume and heating capacity.

MATERIAL SOURCES

Farrell, J. B., et al, "Lime Stabilization of Chemical-Primary Sludge at 1.5 MGD," 45th Annual Conf., WPCF, Atlanta, 1972.

Dotson, G. K., "The Cost of Dewatering and Disposing of Sludge on the Land," Presented AIChE Meeting, November, 1972.

Van Fleet, G. L., "Treatment and Disposal of Chemical Phosphate Sludges in Ontario," 45th Annual Conf., WPCF, Atlanta, 1972.

Ahlberg, N. R., and Boyko, B. I., "Evaluation and Design of Aerobic Digesters," JWPCF, April, 1972.

Stern, Gerald. Various memoes on the Iron Sludge Clinker Problem. January through March, 1973.

"Sludge Processing for Combined Physical-Chemical-Biological Sludges," Central Contra Costa Sanitary District, Walnut Creek, Calif. Project No. R801445, EPA, 1973.

Phillips, James. "The Porteous Process," Adv. Waste Treatment and Water Reuse Symposium, Dallas, Texas, 1971.

State of the Art Review on Sludge Incineration Practice, Water Pollution Control Research Series, No. 17070DIV 04/70. EPA.

"Sludge Handling and Disposal," Technology Transfer Design Seminar Publication, Seminar Held Boston, December, 1972. EPA.

Burd, R. S., "A Study of Sludge Handling and Disposal," EPA (FWPCA) Publication No. WP-20-4, May, 1968.

Weber, Walter, J., Jr., "Physiochemical Processes," Wiley-Interscience, New York, 1972.

Boyko, B. I., and Rupke, J. W. G., "Technical Implementation of Ontario's Phosphorus Removal Program," Ontario Ministry of the Environment, Toronto, Ontario, Canada. (Presented, Purdue Conference, 1973.)

Kehr and Mohle, "Aerobe Oder Anaerobe Schlammbehandlung Auf Klaranlagen," Stadtehygiene, September, 1966.

"Phosphorus Removal by Ferrous Iron and Lime," Water Pollution Control Research Series 110-10-EGO-01/71. EPA.

Table 6a

RECENT PROJECTS -- APRIL 1972

ULTIMATE DISPOSAL

DEMONSTRATION

1.	Land Reclamation Through the Use of Digested Sludge (Chicago MSD)	Continuing
2.	Park Development with Wet Digested Sludge (Metro Seattle)	Completed*
3.	Microbiology of Sewage Sludge Disposal in Soil (Ohio ARS)	Completed*
4.	Development of Treatment and Disposal Methods for Septic Tank Sludges (University of Connecticut)	Completed*
5.	Utilization of Organic Matter in Waste Sludges -- PB 194 784 (Foster D. Snell)	Continuing in-house
6.	Porteous Process for Heat Treatment of Sludge (Lake County, Painesville, Ohio) -- plus in-house treatment of liquor.	Continuing
7.	Evaluation of a Top Feed Rotary Filter (Milwaukee, Wisconsin)	Continuation pending Dec. '72
8.	D.C. Sludge Pilot Plant (District of Columbia)	Continuing
9.	Aerobic Digestion of Sewage Sludge (Hollywood, Florida)	Completed*
10.	Evaluation of Conditioning and Dewatering Sewage Sludge by Freezing -- Published GPO (Milwaukee, Wisconsin)(Not economical)	Completed
11.	Sludge Slurry Pipeline and Strip Mine Reclamation (Morgantown, West Virginia)	Completed*
12.	Application of Enzymes for Sludge Dewatering (Aerojet-General) PB 207 480 (Not economical)	Completed
13.	Fly Ash Aid of Sewage Solids Dewatering and Disposal (Cedar Rapids, Iowa)	Continuing

* Work Completed, Final Report not yet published.

Table 6b

NEW PROJECTS SINCE APRIL 1972

14. Oil Flotation of Sludge (Esso)

15. Capillary Belt Filter (Westinghouse-Infilco)

16. Magnetically Assisted Dewatering of Waste Activated Sludge (R.P. Industries)

17. Lime Sludge Study (Central Contra Costa Sewage Treatment Plant, Walnut Creek, California)

18. Centrate Dewatering Study (LACSD, California)

19. Survey of Land Spreading (Battelle, Columbus, Ohio)

20. Lime Stabilization of Sludge (Battelle-Northwest, Richland, Washington)

21. Phosphate Sludge Disposal in Forest Area (Ely, Minnesota)

Table 7

IN-HOUSE ACTIVITIES

ULTIMATE DISPOSAL

1. Properties of Physical-Chemical Sludges
2. Testing Pilot-Scale Dewatering Equipment
3. Aluminum and Iron Sludges Recovery and Reuse
4. Evaluating Conditioning Sludge with Sludge Ash and Polymers
5. Determining Metals Buildup with Sludge Application
6. Determining Influence of Type of Sludge and Soil on the Growth of Several Plant Types
7. Analyzing for Metals, PCB's, etc., to Determine Quantities and Fate on Disposal
8. Treatment of Liquors from Porteous Process, etc.
9. Task Force on Mercury and Other Heavy Metals in Sludge
10. Task Force on Alternatives to Ocean Dumping

TABLE 5C-1

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS: PRIMARY TREATMENT FOR REMOVAL OF PHOSPHORUS

Sludge Production Parameter		Conventional Primary	Lime Addition to Primary Influent	Lime Addition to Primary Influent	Aluminum Addition to Primary Influent	Iron Addition to Primary Influent
Level of Chemical Addition (mg/l)		0	350–500	800–1,600	13–22.7	25.80
Percent Sludge Solids	Mean	5.25	11.1.	4.4	1.2	2.25
	Range	5.0–5.5	3.0–19.5	2.1–5.5	0.4–2.0	1.0–4.5
lb/mg	Mean	788	5,630	9,567	1,323	2,775
	Range	600–950	2,500–8,000	4,700–15,000	1,200–1,545	1,400–4,500
gal/mg	Mean	4,465	8,924	28,254	23,000	21,922
	Range	3,600–5,000	4,663–18,000	16,787–38,000	10,000–36,000	9,000–38,000

TABLE 5C-2

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS: PHOSPHORUS REMOVAL BY MINERAL ADDITION TO AERATOR

Sludge Production Parameter		Al^{+++} Addition to Aerator: Conventional Secondary	Al^{+++} Addition to Aerator: With Al^{+++} Addition	Fe^{+++} Addition to Aerator: Conventional Secondary	Fe^{+++} Addition to Aerator: With Fe^{+++} Addition
Level of Chemical Addition (mg/l)		0	9.4–23	0	10–30
Percent Sludge Solids	Mean	0.91	1.12	1.2	1.3
	Range	0.58–1.4	0.75–2.0	1.0–1.4	1.0–2.2
lb/mg	Mean	672	1,180	1,059	1,705
	Range	384-820	744–1,462	918–1,200	1,100–2,035
gal/mg	Mean	9,100	13,477	10,650	18,650
	Range	7,250–12,300	7,360–20,000	10,300–11,000	6,000–24,000

TABLE 5C-3

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS: PHOSPHORUS REMOVAL BY MINERAL ADDITION TO SECONDARY EFFLUENT

Sludge Production Parameters		Lime Addition	Alum Addition	Iron Addition
Level of Chemical Addition (mg/l)		268–450	16	10–30
Percent Sludge	Mean	1.1	2.0	0.29
Solids	Range	0.6–1.72	–	–
lb/mg	Mean	4,650	2,000	507
	Range	3,100–6,800	–	175–781
gal/mg	Mean	53,400	12,000	22,066
	Range	50,000–63,000	–	6,000–36,000

LAND APPLICATION OF PROCESSED ORGANIC WASTES

Prepared by

G. M. Wood, P. Eng.,
Supervisor, Planning Section,
Waste Management Branch.

May 28, 1973

Ministry of the Environment,
880 Bay Street,
Toronto, Ontario.

LAND APPLICATION OF PROCESSED ORGANIC WASTES

The Waste Management Branch of the Ministry of the Environment is at the present time undertaking the certification of haulers (organic waste management systems) and organic soil conditioning sites for the disposal of processed organic waste, under the authority of the recent amendments to Regulation 824 of the Revised Regulations of Ontario, 1970.

The implementation of this program is a parallel phase of an overall concept involving re-use, recycling, and reclamation. It is a well established fact that processed organic wastes contain nutrients that are of value to soils and crops and in keeping with Ministry policy, guidelines have been developed in order to make optimum use of this resource asset and at the same time provide the necessary environmental protection criteria.

The potential problems with regard to heavy metal build-up are well recognized, however, present day data is not complete to the point where absolute standards can be applied with regard to concentration etc. As this program developes, more sophisticated techniques will be used to control application rates and appropriate measures will be incorporated as required.

The program will also establish methods and techniques so that the information collected can be evaluated and applied in the future when increased processed organic waste production will call for more efficient operations and more wide spread acceptance of this particular land-use activity.

In terms of the Hauler as Contractor, it will provide a single contact source for Certification of both system and sites. This will preclude the frustrations involved with multi-agency licensing procedures. At the same time, it places the onus on the hauler to maintain his equipment properly, to practice properly controlled spreading techniques and to maintain proper business records as a part of the control phase

of the program.

The hauler is also responsible for providing the necessary area of suitable land and as he is the responsible party to the certification and use of any site, the regulatory and control functions of the Branch are facilitated.

From the amended regulation, "processed organic waste" means waste that is predominantly organic in composition and has been treated by aerobic or anaerobic digestion, or other means of stabilization, and includes sewage residue from water pollution control plants that are subject to the provisions of The Ontario Water Resources Act.

With the recent amendments to Regulation 824, the control of the hauling and disposal of processed organic waste becomes the responsibility of the Waste Management Branch, under the authority of The Environmental Protection Act, 1971, which states in Section 31 that "No person shall use, operate, establish alter, enlarge, or extend,

(a) a waste management system; or

(b) a waste disposal site

unless a certificate of approval or provisional certificate of approval therefore has been issued by the Director and except in accordance with any conditions set out in such certificate." "Director" means the Director of the Waste Management Branch of the Ministry, Section 28(a).

In a report of the Ontario Water Resources Commission (November 1971) on Sewage Sludge Disposal, the following recommendations were made with respect to the growing problem of sewage sludge disposal

(a) the settlement of jurisdictional disputes

(b) a policy regarding a preferred disposal method

(c) the inclusion of processed organic waste disposal sites in plant designs

(d) public relations regarding processed organic waste disposal

(e) the supervision of processed organic waste disposal

(f) research regarding land application

and (g) control of disposal sites

The inclusion of processed organic waste disposal sites in plant designs is being implemented by the Plant Operations Branch of the Ministry and continuing research programs regarding land application are being carried out for the Branch by the Department of Land Resource Sciences of the University of Guelph.

An area which must be explored further is in regard to public relations, particularly with respect to municipal officials and the agricultural community, as well as, the general public. The agricultural community is well served by the research carried out at Guelph University, as these expert opinions are valued. The Ministry of Agriculture and Food through their regular publications and extension courses, also contributes greatly to aspects of waste management. Some concern addresses itself to the passing of prohibitive land-use by-laws excluding this type of activity. It is hoped that publication of the results of our research will help alleviate this area of concern.

From the recent amendment to Regulation 824, "the following are prescribed as standards for the location, maintenance and operation of an organic soil conditioning site.

1. The site shall be so located that it is an adequate distance from any watercourse, as determined by land slope, to prevent direct surface drainage to the watercourse.

2. The site shall be at least 300 feet from the nearest individual dwelling.

3. The site shall be at least 1,500 feet from any area of residential development.

4. The site shall be so located that the maximum level of the ground water table at the site is at a sufficient distance below the surface to prevent the impairment of groundwater in aquifers as determined by the permeability of the soil.

5. The site shall be at least 300 feet from any water well.

6. No processed organic waste shall be applied to the site during any period in which conditions are such that surface runoff is likely to occur taking into account land slope, soil permeability and the climatic conditions of the area.

7. The site shall be established only on land that is, or is intended to be, used for pasture, fallow or the growing of forage crops,

(a) during the current growing season, or

(b) where application of the processed organic waste is made sometime after the current growing season, to the end of the site sequent growing season.

8. Berms and dykes of low permeability shall be constructed on the site where necessary to isolate the site and effectively prevent the egress of contaminants.

In addition to the Regulations, these additional comments are found in the "Guidelines for Disposal of Sludge by Land Application".

1. Site Location

1.1 The site should be remote from surface water courses. The min. distance between the site and the surface water course should be determined by the land slope as follows:

Max. Sustained Slope	Minimum Distance to Watercourse: For Sludge Application During May to Nove. inclusive	For Sludge Application During Dec. to Apr. inclusive
0 to 3%	200 ft.	600 ft.
3 to 6%	400 ft.	600 ft.
6 to 9%	600 ft.	No sludge to be applied
greater than 9%	No sludge to be applied unless special conditions exist	No sludge to be applied

NOTE: "SLUDGE" means "PROCESSED ORGANIC WASTE" in the Guidelines.

2. Land Characteristics

2.1. The land slope and soil permeability will determine the time of year that sludge may be applied. The soil permeability classification shall be in accordance with Tables 1. and 2. of the Ministry of Agriculture & Food's publication entitled "Drainage Guide for Ontario". The type of soil will be determined with the use of County Soil Maps available through the Ministry of Agriculture & Food.

Max. Sustained	Soil Permeability	Allowable Duration of Application	
		Southern Ont.	Northern Ont.
0 to 3%	any	12 mon/yr.	12 mon/yr.
3 to 6%	rapid to moderately rapid	12 mon/yr.	12 mon/yr.
	moderate to slow	10 mon/yr. (May to Feb.)	9 mon/yr. (June to Feb.)
6 to 9%	rapid to moderately rapid	7 mon/yr. (May to Nov.)	6 mon/yr. (June to Nov.)
	moderate to slow	6 mon/yr. (May to Oct.)	5 mon/yr. (June to Oct.)
Greater than 9%	any	No sludge application unless warranted by special conditions	

2.2. The ground water table during sludge application should be not less than 3.0 ft. from the surface for soils with moderate to slow permeability. For soils with rapid to moderately rapid permeability the ground water table should be not less than 5.0 ft. from the surface.

2.3 Where sludge application is carried out by tank truck, untiled land should be given preference to tiled land. Where tiled land is used the sludge hauling contractor should request instructions from the landowner, with regards to minimizing the possibility of damage to the tile system.

3. Site Management

3.1 When sludge is applied to agricultural land, the land is to be used only for pasture, fallow or the growing of forage crops. Dairy cattle should be excluded from pasture land. These restrictions on land use shall apply from the date of application until the end of the calendar year during which the sludge has been applied.

3.2 The boundaries of the site shall be marked (eg. with stakes at corners) so as to avoid confusion regarding the location of the site during sludge application, or during the taking of soil or crop samples. The markers should be maintained until the end of the current or subsequent growing season, whichever is applicable.

3.3 Soil tillage and sludge application, should where possible, follow the contours of the land (to maintain a contour furrow system). Passage of sludge spreading vehicles over the land should be minimized, to reduce compaction of the soil (eg. the allowable sludge application rate in cu. yds./A/yr., could be achieved after one or two passes).

3.4 Special precautions may be required where the possibility of localized surface water runoff problems exist.

4. Sludge Application Rates

4.1 In determining the allowable rate of sludge application for a particular parcel of land, the objective shall be to match as closely as possible the quantity of nutrients removed from the soil by the harvesting of the crop. The allowable rate will thus be determined by the nutrient content of the particular sludge and the nutrient uptake capabilities of the particular crop under consideration.

The sludge hauling contractor shall adhere to the application rate (in cu. yd./A/yr.) specified in the Certificate of Approval issued by the Waste Management Branch of the Ministry of the Environment. The suitability of sludge application rates may if required be monitored by soil analyses and/or crop analyses. The collection of soil or crop samples shall be the responsibility of the Waste Management Branch.

4.2 The sludge shall be spread uniformly over the surface of the land.

4.3 The sewage treatment plant operating agency is to keep records of the location of all the sites used for the disposal of its sludge and the sludge quantities disposed of at each site, each week (eg. volume of sludge in cu. yds., and weight of sludge solids in tons). The operating agency shall ensure that at least every 3 months, samples of the sludge are submitted for thorough analysis (eg. total solids, volatile solids, pH, nitrogen, phosphorus, potassium, ether extractables, heavy metals, etc.).

With regard to processed organic waste application rates, until further information is available to the Branch regarding possible problems with respect to heavy metals build-up in the soil, the equivalent application rate of 200 lb. of nitrogen/acre/year will be used. Processed organic waste may be applied at the rate of 400 lb. nitrogen/acre if application is to be made every second year. These application rates are at the suggestion of the research group at the University of Guelph. We believe the rate of 200 lb. nitrogen/acre/year is a very conservative figure as the Ministry of Agriculture and Food suggests a maximum of 300 lb. nitrogen/acre/year for the land application of farm wastes.

In the future, it is felt that application rates will be based on heavy metals with the idea of preventing the build-up of levels which may be toxic to both plant growth and the implications of transfer by ingestion. Recent research in England suggests maximum permissible levels of the metals zinc, copper and nickel in processed organic waste applied to agricultural land of 250 mg/kg zinc equivalent at soil pH's above 6.5. Soil pH is important as heavy metals are locked within the soil at a pH 7 or above and can be leached out at pH's below 7. Evidence indicates copper to be twice as toxic as zinc and nickel to be eight times as toxic as zinc. Zinc, copper and nickel are the elements most likely to give rise to toxicity problems in plants due to the use of processed organic waste as a soil additive.

With the recent addition of phosphorus removal at some water pollution control plants, the quantity of processed organic waste has increased and the chemicals used to remove phosphorus may have some impact on the present disposal practices. At the present time lime, alum, and ferric chloride are proposed for nutrient removal. There is some concern that the addition of alum and ferric chloride to processed organic waste may depress the pH to an extent where the heavy metals may leach out into the groundwater. This problem is presently under study at the University of Guelph.

Licensing procedures have been developed so that the following steps will be carried out. The processed organic waste hauler will request application and supporting information forms for organic waste management system and organic soil conditioning site or sites from a Branch Regional Office. On notifying the Regional Office that he has received a contract, the Branch will then proceed to inspect the equipment and proposed sites. If the sites prove unsatisfactory, the hauler will be requested to locate additional satisfactory sites. The Regional Office will also consult other pertinent agencies for their technical inputs on a particular site or system, (Sanitary Engineering, Air Management, Agriculture, (site only) the local Medical Officer of Health, and local municipal authorities). The application and supporting information forms for satisfactory system and each satisfactory site will then be sent to the head office along with the Regional Engineer's Recommendation. The head office will then issue a Certificate of Approval for the system and each site for a maximum period of one year.

The staff in the Regional Offices will be required to take soil and crop samples at each site at least once a year. These samples will be analysed for nutrient build-up and for some sites, heavy metal buildup. The sites for processed organic waste from water pollution control plants which are known to contain levels of heavy metals which may be of concern, will be the initial sites analysed for heavy metal buildup. It is anticipated that when a new site is licensed, a soil sample will be taken

for analysis to provide a basis to check on possible buildup of nutrients and heavy metals. Should a problem buildup occur, a stop order for use of the site would be issued immediately.

While this program has a very specific regulatory function and appears to limit present day practices, it is, indeed, designed to provide an acceptable method of:

(a) solving a plant disposal problem

(b) making use of hitherto wasted nutrient values under controlled conditions

The enforcement of this regulation will be approached on the basis that a solution to an existing problem must be found and that a co-operative effort will be sought from all those presently working in this area. It is possible that certain haulers will not be able to meet these requirements or will refuse to do so. Under The Environmental Protection Act, 1971 and these regulations, it will be impossible for a water pollution control plant to enter into a valid contractual commitment with any hauler who does not have a Certificate of Approval from this Branch. An almost immediate consequence of this will be to screen out those who either cannot or will not meet the requirements.

This will further assist in establishing acceptable Codes of Practice.

It is also hoped that this concern with solid waste management systems will be reflected in all aspects of planning and design of future processing facilities and that the additional costs that must arise from the up-grading of this management practice will be willingly accepted as a necessary contribution to the protection of the land.

APPENDICES

A - Regulation Made Under the Waste Management Act - (Regulation 824-Revised Regulations of Ontario, 1970) Toronto, December, 1972.

B - Ontario Regulation 217/73 - April 12, 1973 - Revisions to Regulation 824.

C - Interim Guidelines for Processed Organic Waste Hauling and Spreading Equipment.

D - Effects on Crops of Toxic Metals in Processed Organic Waste.

E - Interim Guidelines For Disposal of Sludge by Land Application.

APPENDIX A

Ontario

Regulation Made Under The Waste Management Act

GENERAL

Regulation 824

Revised Regulations of Ontario, 1970

DECEMBER 1972

TORONTO
PRINTED AND PUBLISHED BY THE QUEEN'S PRINTER AND PUBLISHER

13

OFFICE CONSOLIDATION

THIS EDITION IS PREPARED FOR PURPOSES OF CONVENIENCE ONLY, AND FOR ACCURATE REFERENCE RECOURSE SHOULD BE HAD TO THE OFFICIAL VOLUMES.

REGULATION 824

under The Waste Management Act

GENERAL

INTERPRETATION

1. In this Regulation,

1. "abandoned motor vehicle" means a motor vehicle abandoned on public or private property and includes such part of a motor vehicle that is left after salvaging;

2. "access road" means a road that leads from a public road to a waste disposal site;

3. "agricultural waste" means waste, other then sewage, resulting from farm operations, including animal husbandry and where a farm operation is carried on in respect of food packing, food preserving, animal slaughtering or meat packing, includes the waste from such operations;

4. "cell", in respect of a landfilling site, means a deposit of waste that has been sealed by cover material so that no waste deposited in the cell is exposed to the atmosphere;

5. "composting" means the treatment of waste by aerobic decomposition of organic matter by bacterial action for the production of stabilized humus;

6. "cover material" means soil or other material approved for use in sealing cells in landfilling;

7. "dead animal" means an animal that dies naturally or from disease or by reason of accident and includes parts thereof;

8. "dump" means a waste disposal site where waste is deposited without cover material being applied at regular intervals;

9. "fly-ash" means particulate matter removed from combustion flue gases;

10. "grinding" means the treatment of waste by uniformly reducing the waste to particles of controlled maximum size;

11. "hauled liquid and hazardous waste collection system" means a waste management system or any part thereof for the collection, handling, transportation, storage or processing of hauled liquid industrial waste or hazardous waste but does not include the disposal thereof;

12. "hauled liquid industrial waste" means liquid waste, other than hauled sewage, that results from industrial processes or manufacturing or commercial operations and that is transported in a tank or other container for treatment or disposal, and includes sewage residue from sewage works that are subject to the provisions of *The Ontario Water Resources Commission Act*;

13. "hauled sewage" meahs waste removed from,
    i. a cesspool,
    ii. a septic tank system,
    iii. a privy-vault or privy pit,
    iv. a chemical toilet,
    v. a portable toilet, or
    vi. a sewage holding tank at a marina,

    and transported in a tank or other container for treatment or disposal other than at a waste disposal site;

14. "hazardous waste" means waste that requires special precautions in its storage, collection, transportation, treatment or disposal, to prevent damage to persons or property and includes explosive, flammable, volatile, radioactive, toxic and pathological waste;

15. "incineration" means the treatment of waste by controlled burning, including measures for limiting air pollution, to reduce the volume of the waste and to leave it in a more stable form for disposal;

16. "incinerator ash" means the ash residue, other than fly-ash, resulting from incineration where the waste is reduced to ashes containing by weight less than 10 per cent of combustible materials;

17. "incinerator waste" means the residue from incineration, other than incinerator ash and fly-ash;

18. "inert fill" means earth or rock fill that contains no putrescible materials or soluble or decomposable chemical substances;

19. "individual collection system" means the collection of his own domestic wastes by a householder and the transportation of such wastes to a waste disposal site by the householder;

20. "landfilling" means the disposal of waste by deposit, under controlled conditions, on land or on land covered by water, and includes compaction of the waste into a cell and covering the waste with cover materials at regular intervals;

21. "marine craft waste disposal system" means a waste disposal system operated by a person or a municipality for the receiving of waste from marine craft for deposit in holding tanks;

22. "municipal waste management system" means a waste management system, or any part thereof, of which a municipality is the owner;

23. "on-site garbage grinder" means a grinder,

  i. used for the treatment of waste that is subsequently discharged as sewage, and

  ii. located in a building or structure used principally for functions other than waste management;

24. "on-site incinerator" means an incinerator that is located in a building or structure used principally for functions other than waste management;

25. "on-site road" means a road for the movement of vehicles and equipment within a waste disposal site;

26. "packing and baling" means the treatment of waste by its compression into blocks or bales and binding or sheating the blocks with wire, metal, plastic or other material;

27. "private waste management system" means a waste management system, or any part thereof, of which a person other than a municipality is the owner;

28. "scavenging" means the uncontrolled removal of reusable material from waste at a waste disposal site;

29. "transfer station" means a waste disposal site used for the purpose of transferring waste from a collection vehicle to another carrier for transportation to another waste disposal site. R.R.O. 1970, Reg. 824, s. 1.

DESIGNATION AND EXEMPTION OF WASTES

2. The following are designated wastes:

1. Abandoned motor vehicles.
2. Agricultural wastes.
3. Condemned animals or parts thereof at a plant licensed under *The Meat Inspection Act (Ontario)*, or an establishment operating under the *Meat Inspection Act* (Canada).
4. Dead animals.
5. Hauled liquid industrial waste.
6. Hauled sewage.
7. Hazardous waste.
8. Incinerator waste.
9. Inert fill.
10. Rock fill or mill tailings from a mine. R.R.O. 1970, Reg. 824, s. 2.

3. The following wastes are exempted from the Act and this Regulation:

1. Abandoned motor vehicles.
2. Agricultural wastes.
3. Condemned animals or parts thereof at a plant licensed under *The Meat Inspection Act (Ontario)* or an establishment operating under the *Meat Inspection Act* (Canada).
4. Dead animals to which *The Dead Animal Disposal Act* applies.
5. Hauled sewage.
6. Inert fill.
7. Rock fill or mill tailings from a mine. R.R.O. 1970, Reg. 824, s. 3.

CLASSIFICATION AND EXEMPTION OF WASTE DISPOSAL SITES

4. Waste disposal sites are classified as follows:

1. Composting sites.
2. Dumps.
3. Grinding sites.

4. Incineration sites.
5. Landfilling sites.
6. On-site incinerators.
7. On-site garbage grinders.
8. Packing and baling sites.
9. Transfer stations. R.R.O. 1970, Reg. 824, s. 4.

5. The following waste disposal sites are exempted from the Act and this Regulation:

1. On-site incinerators.
2. On-site garbage grinders. R.R.O. 1970, Reg. 824, s. 5.

CLASSIFICATION AND EXEMPTION OF WASTE MANAGEMENT SYSTEMS

6. Waste management systems are classified as follows:

1. Municipal waste management systems.
2. Private waste management systems.
3. Individual collection systems.
4. Hauled liquid and hazardous waste collection systems.
5. Marine craft waste disposal systems. R.R.O. 1970, Reg. 824, s. 6.

7. The following waste management systems are exempted from the Act and this Regulation:

1. Individual collection systems.
2. Marine craft waste disposal systems. R.R.O. 1970, Reg. 824, s. 7.

CERTIFICATES OF APPROVAL FOR WASTE DISPOSAL SITES AND WASTE MANAGEMENT SYSTEMS

8. A certificate of approval for a waste disposal site or a waste management system or a renewal thereof expires one year after the date upon which the certificate or renewal is issued. R.R.O. 1970, Reg. 824, s. 8.

9. A provisional certificate of approval for a waste disposal site or a waste management system or a renewal thereof expires on the date shown thereon. R.R.O. 1970, Reg. 824, s. 9.

STANDARDS FOR WASTE DISPOSAL SITES

10.—(1) The following are prescribed as standards for the location, maintenance and operation of a landfilling site that are to be met to the satisfaction of the Minister by an applicant for a certificate of approval therefor:

1. Access roads and on-site roads shall be provided so that vehicles hauling waste to and on the site may travel readily on any day under all normal weather conditions.
2. Access to the site shall be limited to such times as an attendant is on duty and the site shall be restricted to use by persons authorized to deposit waste in the fill area.
3. Drainage passing over or through the site shall not adversely affect adjoining property and natural drainage shall not be obstructed.
4. Drainage that may cause pollution shall not, without adequate treatment, be discharged into watercourses.
5. Waste shall be placed sufficiently above or isolated from the maximum water table at the site in such manner that impairment of groundwater in aquifers is prevented and sufficiently distant from sources of potable water supplies so as to prevent contamination of the water, unless adequate provision is made for the collection and treatment of leachate.
6. Where required by the Minister, adequate measures to prevent water pollution shall be taken by the construction of berms and dykes of low permeability to isolate the site and effectively prevent the egress of pollutants.
7. Where required by the Minister, samples shall be taken and tests made to measure the extent of egress of pollutants and such measures as are required by the Minister shall be taken for the collection and treatment of pollutants and for the prevention of water pollution.
8. The site shall be located a reasonable distance from any cemetery.
9. Adequate and proper equipment shall be provided for the compaction of waste into cells and the covering of the cells with cover material.
10. Where climatic conditions may prevent the use of the site at all times, provisions shall be made for another waste disposal site which can be used during such periods.
11. Where required for accurate determination of input of all wastes by weight, scales shall be provided at the site or shall be readily available for use.

12. All waste disposal operations at the site shall be adequately and continually supervised.

13. Waste shall be deposited in an orderly manner in the fill area, compacted adequately and covered by cover material by a proper landfilling operation.

14. Procedures shall be established for the control of rodents or other animals and insects at the site.

15. Procedures shall be established, signs posted, and safeguards maintained for the prevention of accidents at the site.

16. The waste disposal area shall be enclosed to prevent entry by unauthorized persons and access to the property shall be by roadway closed by a gate capable of being locked.

17. A green belt or neutral zone shall be provided around the site and the site shall be adequately screened from public view.

18. Whenever any part of a fill area has reached its limit of fill, a final cover of cover material shall be placed on the completed fill and such cover shall be inspected at regular intervals over the next ensuing period of two years and where necessary action shall be taken to maintain the integrity and continuity of the cover materials.

19. Scavenging shall not be permitted.

(2) A certificate of approval for a landfilling site is subject to the condition that the site shall continue to be maintained and operated in accordance with the standards approved therefor. R.R.O. 1970, Reg. 824, s. 10.

11.—(1) The following are prescribed as standards for the location, maintenance and operation of an incineration site that are to be met to the satisfaction of the Minister by an applicant for a certificate of approval therefor:

1. The location of the incineration site shall be selected so as to reduce the effects of nuisances, such as dust, noise, and traffic.

2. Incinerator waste shall be disposed of at a landfilling site.

3. The incinerator shall be located,

(*a*) so that it is accessible for the transportation of wastes thereto without nuisance;

(*b*) taking into account meteorological considerations to minimize environmental effects; and

(*c*) so that the services and utilities required for the operation of the incinerator are available, including facilities for the disposal or residue and of quenching and scrubbing water.

4. The design and capacity of the incinerator shall be in accordance with accepted engineering practices and of a type and size adequate to efficiently process the quantities of waste that may be expected, so that a minimum volume of residue is obtained, the putrescible materials remaining as residue are reduced to a minimum and a minimum of air pollution results.

5. The following equipment shall be provided as required for particular applications to the satisfaction of the Minister:

i. Scales for the accurate determination of the input of all wastes by weight.

ii. A storage pit or other storage facilities.

iii. A crane or other means of removing waste from the pit or other storage facilities.

iv. Means of controlling dusts and odours.

v. Such instruments as may be necessary for the efficient operation of an incinerator.

6. The incineration site shall include an unloading area properly enclosed and of sufficient size for the intended operation.

7. Access roads shall be provided for vehicles hauling waste to the incineration site.

8. On-site fire protection shall be provided and, where possible, arrangements shall be made with a fire department or municipality for adequate fire fighting services in case of an emergency.

9. Scavenging shall not be permitted.

(2) A certificate of approval for an incineration site is subject to the condition that the site shall continue to be maintained and operated in accordance with the standards approved therefor. R.R.O. 1970, Reg. 824, s. 11.

12.—(1) The following are prescribed as the standards for the location, maintenance and operation of a dump that are to be met to the satisfaction of the Minister by an applicant for a certificate of approval therefor:

1. The fill area shall not be subject to flooding and shall be so located that no direct drainage leads to a watercourse.

2. The site shall be at least one-quarter of a mile from the nearest dwelling.

3. The site shall be at least two hundred yards from the nearest public road.

4. The site shall be at least 100 feet from any watercourse, lake or pond.

5. The site shall not be on land covered by water.

6. Signs shall be posted stating requirements for the operation of the dump, including measures for the control of vermin and insect infestation.

7. The site shall be so located and operated as to reduce to a minimum the hazards resulting from fire.

8. The operator of the dump shall apply such cover material at such intervals as the Medical Officer of Health may direct.

9. Scavenging shall not be permitted.

(2) A certificate of approval for a dump is subject to the condition that the dump shall continue to be maintained and operated in accordance with the standards approved therefor. R.R.O. 1970, Reg. 824, s. 12.

13.—(1) Subject to subsection 2, no dump shall be established or operated in a city, borough, town, separated town, township, village or police village in any county, regional municipality or the Provisional County of Haliburton.

(2) Notwithstanding subsection 1, a dump may be established in the following parts of Ontario:

1. The townships of Albermarle, Eastnor, Lindsay and St. Edmunds, in the County of Bruce.

2. The townships of Barrie, Bedford, Clarendon and Miller, Howe Island, Kennebec, Olden, and Palmerston and North and South Canonto, in the County of Frontenac.

3. The townships of Bangor, Wicklow and McClure, Carlow, Dungannon, Elzevir and Grimsthorpe, Herschel, Limerick, Madoc, Marmora and Lake, Mayo, Monteagle, Tudor and Cashel, and Wollaston, in the County of Hastings.

4. The townships of Dalhousie and North Sherbrooke, Darling, Lavant, North Burgess, and South Sherbrooke, in the County of Lanark.

5. The townships of Asphodel, Belmont and Methuen, Chandos, Ennismore, Galway and Cavendish, and Harvey, in the County of Peterborough.

6. The townships of Bagot and Blithfield, Brougham, Brudenell and Lyndock, Griffith and Matawatchan, Head, Clara, and Maria, North Algona, Radcliffe, Raglan, Sebastopol, and South Algona, in the County of Renfrew.

7. The townships of Carden, Dalton, and Laxton, Digby and Longford, in the County of Victoria.

8. The Improvement District of Bicroft, the townships of Anson, Hindon and Minden, Cardiff, Dysart, Bruton, Clyde, Dudley, Eyre, Guilford, Harburn, Harcourt and Havelock, Glamorgan, Lutterworth, Monmouth, Sherborne, McClintock, Livingstone, Lawrence and Nightingale, and Snowdon and Stanhope, in the Provisional County of Haliburton.

(3) No dump shall be established or operated in the following parts of the territorial districts of Ontario:

1. The City of Sault Ste. Marie, the town of Blind River, Bruce Mines, and Thessalon, the villages of Hilton Beach and Iron Bridge, and the Township of Elliot Lake, in the Territorial District of Algoma.

2. The towns of Cochrane, Hearst, Iroquois Falls, Kapuskasing, Matheson, Smooth Rock Falls, and Timmins, and the townships of Glackmeyer, Mountjoy, Tisdale and Whitney, in the Territorial District of Cochrane.

3. The towns of Dryden, Keewatin, Kenora, and Sioux Lookout, and the townships of Jaffray and Melick, in the Territorial District of Kenora.

4. The towns of Gore Bay and Little Current, in the Territorial District of Manitoulin.

5. The towns of Bala, Bracebridge, Gravenhurst, and Huntsville, and the villages of Port Carling, Port Sydney and Windermere, in the Territorial District of Muskoka.

6. The City of North Bay, the towns of Bonfield, Cache Bay, Mattawa, and Sturgeon Falls, and the townships of East Ferris, Field and Springer, in the Territorial District of Nipissing.

7. The towns of Kearney, Parry Sound, Powassan and Trout Creek, the villages of Burk's Falls, Magnetawan, Rosseau, South River and Sundridge, and the townships of Foley, McDougall, North Himsworth, and South Himsworth, in the Territorial District of Parry Sound.

8. The towns of Fort Frances and Rainy River, and the Township of Atikokan, in the Territorial District of Rainy River.

9. The City of Sudbury, the towns of Capreol, Coniston, Copper Cliff, Espanola, Levack, Lively, Massey and Webbwood, and the townships of Balfour, Falconbridge, and Neelon and Garson, in the Territorial District of Sudbury.

10. The City of Thunder Bay, the Town of Geraldton and the townships of Neebing, Nipigon, Oliver, Paipoonge, Schreiber, Shuniah, and Terrace Bay, and the improvement districts of Beardmore, Manitouwadge, Nakina, and Red Rock, in the Territorial District of Thunder Bay.

11. The towns of Charlton, Cobalt, Englehart, Haileybury, Latchford, and New Liskeard, the Village of Thornloe, and the townships of Armstrong, Bucke, Larder Lake, McGarry, and Teck, in the Territorial District of Timiskaming. R.R.O. 1970, Reg. 824, s. 13.

STANDARDS FOR WASTE MANAGEMENT SYSTEMS

14.—(1) The following are standards for the operation of a waste management system that are to be met to the satisfaction of the Minister by an applicant for a certificate of approval therefor:

1. All waste collection vehicles and waste carriers shall be so constructed as to enable waste to be transferred safely and without nuisance from storage containers to the vehicle.

2. Bodies of waste collection vehicles and waste carriers shall be so constructed as to withstand abrasion and corrosion from the waste.

3. Bodies of waste collection vehicles and waste carriers shall be leakproof and covered where necessary to prevent the emission of offensive odours, the falling or blowing of waste material from the vehicles or the release of dust or other air-borne materials that may cause air pollution.

(2) A certificate of approval for a waste management system is subject to the condition that the system shall continue to be operated in accordance with the standards approved therefor. R.R.O. 1970, Reg. 824, s. 14.

APPENDIX B

REGULATION MADE UNDER THE ENVIRONMENTAL PROTECTION ACT, 1971

1. Section 1 of Regulation 824 of Revised Regulations of Ontario, 1970 is amended by adding thereto the following paragraphs:

> 25a. "organic soil conditioning" means the incorporation of processed organic waste in the soil to improve its characteristics for crop or ground cover growth;
>
> . . . . .
>
> 27a. "processed organic waste" means waste that is predominantly organic in composition and has been treated by aerobic or anaerobic digestion, or other means of stabilization, and includes sewage residue from sewage works that are subject to the provisions of The Ontario Water Resources Act;

2. Section 2 of Regulation 824 of Revised Regulations of Ontario, 1970 is amended by adding thereto the following item:

> 9a. Processed organic waste.

3. Section 4 of Regulation 824 of Revised Regulations of Ontario, 1970 is amended by adding thereto the following item:

> 7a. Organic soil conditioning site.

4. Section 6 of Regulation 824 of Revised Regulations of Ontario,1970 is amended by adding thereto the following item:

6. Organic waste management system.

5.-(1) Subsection 1 of section 10 of Regulation 824 of Revised Regulations of Ontario, 1970, exclusive of the paragraphs, is revoked and the following substituted therefor:

(1) The following are prescribed as standards for the location, maintenance and operation of a landfilling site:

(2) Paragraphs 6 and 7 of subsection 1 of the said section 10 are revoked and the following substituted therefor:

6. Where necessary to isolate a landfilling site and effectively prevent the egress of contaminants, adequate measures to prevent water pollution shall be taken by the construction of berms and dykes of low permeability.

7. Where there is a possibility of water pollution resulting from the operation of a landfilling site, samples shall be taken and tests made by the owner of the site to measure the extent of egress of oontaminants and, if necessary, measures shall be taken for the collection and treatment of contaminants and for the prevention of water pollution.

(3) Subsection 2 of the said section 10 is revoked.

6.-(1) Subsection 1 of section 11 of Regulation 824 of Revised Regulations of Ontario, 1970, exclusive of the paragraphs, is revoked and the following substituted therefor:

(1) The following are prescribed as standards for the location, maintenance and operation of an incineration site:

(2) Paragraph 5 of subsection 1 of the said section 11, exclusive of the subparagraphs, is revoked and the following substituted therefor:

5. The following equipment shall be provided as necessary for particular applications:

(3) Subsection 2 of the said section 11 is revoked.

7.-(1) Subsection 1 of section 12 of Regulation 824 of Revised Regulations of Ontario, 1970, exclusive of the paragraphs, is revoked and the following substituted therefor:

(1) The following are prescribed as standards for the location, maintenance and operation of a dump:

(2) Paragraph 8 of subsection 1 of the said section 12 is revoked and the following substituted therefor:

8. The operator of a dump shall apply such cover material at such intervals as is necessary to prevent harm or material discomfort to any person.

(3) Subsection 2 of the said section 12 is revoked.

8.-(1) Subsection 1 of section 14 of Regulation 824 of Revised Regulations of Ontario, 1970, exclusive of the paragraphs, is revoked and the following substituted therefor:

> (1) The following are prescribed as standards for the operation of a waste management system:

(2) Subsection 2 of the said section 14 is revoked.

9. Regulation 824 of Revised Regulations of Ontario, 1970 is amended by adding thereto the following section:

> 13a. The following are prescribed as standards for the location, maintenance and operation of an organic soil conditioning site:
>
> 1. The site shall be so located that it is in an adequate distance from any watercourse, as determined by the land slope, to prevent direct surface drainage to the watercourse.
> 2. The site shall be at least 300 feet from the nearest individual dwelling.
> 3. The site shall be at least 1,500 feet from any area of residential development.
> 4. The site shall be so located that the maximum level of the ground water table at the site is at a sufficient distance below the surface to prevent the impairment of ground water in aquifers as determined by the permeability of the soil.

5. The site shall be at least 300 feet from any water wells.

6. No processed organic waste shall be applied to the site during any period in which conditions are such that surface runoff is likely to occur taking into account land slope, soil permeability and the climatic conditions of the area.

7. The site shall be established only on land that is, or is intended to be, used for pasture, fallow or the growing of forage crops,

   a. during the current growing season, or

   b. where application of the processed organic waste is made sometime after the current growing season, to the end of the subsequent growing season.

8. Berms and dykes of low permeability shall be constructed on the site where necessary to isolate the site and effectively prevent the egress of contaminants.

APPENDIX C

INTERIM GUIDELINES FOR PROCESSED ORGANIC WASTE HAULING AND SPREADING EQUIPMENT

1. Equipment should be maintained in good working order at all times and should be cleaned on a regular basis.

2. Before the tank can be used for any other purpose, permission must be obtained from the appropriate authority.

3. The processed organic waste should be spread at least as wide as the spreading equipment.

4. Some method should be provided to control the spreading valve by the driver of the spreading equipment while vehicle is in motion.

5. The spreading valve should not be opened until the spreading equipment is in motion.

6. The spreading valve should be of the "fail safe" (ie., self closing) or an additional manual standby valve should be employed to prevent the uncontrolled spreading of the processed organic waste.

7. Care should be taken under windy conditions to avoid spreading out of the approved area.

8. The hauling equipment should be so designed to prevent the possibility of spillage, the dissemination of odours, and other public nuisances during transport.

9. If the processed organic waste is transferred from the hauling equipment to separate spreading equipment, the transfer should be carried out under controlled conditions to preclude spillage.

APPENDIX D

EFFECTS ON CROPS OF TOXIC METALS IN PROCESSED ORGANIC WASTE

A recent paper by J. Webber, Agricultural Development and Advisory Service at Leeds in the Water Pollution Control Journal, Volume 71, No. 4, 1972 gives representative toxicity data summarized as follows:

1) Zinc, copper and nickel are the elements most likely to give rise to toxicity problems in plants due to the use of processed organic waste as a soil additive. Chromium toxicity has been indicated in some instances.

2) It is generally not possible to diagnose heavy metal toxicity from the observation of crop symptoms.

3) Toxic effects of all metals, except perhaps of anionic chromium (i.e. potassium chromate), are reduced at pH levels above 6.5.

4) Toxicity symptoms due to zinc appear at levels of 125 mg/kg available zinc.

5) With cereal crops toxicity due to copper will appear at levels of 200 mg/kg in an acid soil of pH 5.2 and at levels of 400 mg/kg at a pH of 6.8.

6) Toxic effects of nickel become prominent at levels in excess of 50 mg/kg soil.

7) Webber suggests maximum permissible levels of the metals zinc, copper and nickel in sludge applied to agricultural land of 250 mg/kg zinc equivalent at soil pH's above 6.5. Evidence indicates copper to be twice as toxic as zinc and nickel to be 8 times as toxic as zinc.

APPENDIX E

INTERIM GUIDELINES FOR DISPOSAL OF SLUDGE BY LAND APPLICATION

NOTE

a) The following pertains to the disposal of sludge which had undergone proper anaerobic or aerobic digestion or other suitable processing, at a municipal sewage treatment plant.

b) It is intended that the method of land application entail the utilization of sludge in the agricultural industry, as opposed to merely disposing of the material.

1. Site Location

1.1 The site should be remote from surface water courses. The min. distance between the site and the surface water course should be determined by the land slope as follows:

Max. Sustained Slope	Minimum Distance to Watercourse: For Sludge Application During May to Nov. inclusive	For Sludge Application During Dec. to Apr. inclusive
0 to 3%	200 ft.	600 ft.
3 to 6%	400 ft.	600 ft.
6 to 9%	600 ft.	No sludge to be applied
greater than 9%	No sludge to be applied unless special conditions exist	No sludge to be applied

1.2 The site shall be at least 300 ft. from individual human habitations.

1.3 The site shall be at least 300 ft. from water wells.

1.4 The site shall be at least 1,500 ft. from areas of residential development.

2. Land Characteristics

2.1 The land slope and soil permeability will determine the time of year that sludge may be applied, as follows:

Max. Sustained Slope	Soil Permeability**	Allowable Duration of Application Southern Ont.	Northern Ont.
0 to 3%	any	12 mon/yr.	12 mon/yr.
3 to 6%	rapid to moderately rapid	12 mon/yr.	12 mon/yr.
	moderate to slow	10 mon/yr. (May to Feb.)	9 mon/yr. (June to Feb.)
6 to 9%	rapid to moderately rapid	7 mon/yr. (May to Nov.)	6 mon/yr. (June to Nov.)
	moderate to slow	6 mon/yr. (May to Oct.)	5 mon/yr. (June to Oct.)
greater than 9%	any	No sludge application unless warranted by special conditions	

** Soil permeability classification shall be in accordance with Tables 1. and 2. of the Ministry of Agriculture & Food's publication entitled "Drainage Guide for Ontario" (See Appendix 1.). The type of soil should be determined with the use of County Soil Maps available through the Ministry of Agriculture & Food.

2.2 The ground water table during sludge application should be not less than 3.0 ft. from the surface for soils with moderate to slow permeability. For soils with rapid to moderately rapid permeability the ground water table should be not less than 5.0 ft. from the surface.

2.3 Where sludge application is carried out by tank truck, untiled land should be given preference to tiled land. Where tiled land is used the sludge hauling contractor should request instructions from the landowner, with regards to minimizing the possibility of damage to the tile system.

3. Site Management

3.1 When sludge is applied to agricultural land, the land is to be used only for pasture, fallow or the growing of forage crops. Dairy cattle should be excluded from pasture land. These restrictions on land use shall apply from the date of application until the end of the calendar year during which the sludge has been applied.

3.2 The boundaries of the site shall be marked (eg. with stakes at corners) so as to avoid confusion regarding the location of the site during sludge application, or during the taking of soil or crop samples. The markers should be maintained until the end of the current or subsequent growing season, whichever is applicable.

3.3 Soil tillage and sludge application, should where possible, follow the contours of the land (to maintain a contour furrow system). Passage of sludge spreading vehicles over the land should be minimized, to reduce compaction of the soil (eg. the allowable sludge application rate in cu. yds./A/yr., could be achieved after one or two passes).

3.4 Special precautions may be required where the possibility of localized surface water runoff problems exist.

4. Sludge Application Rates

4.1 In determining the allowable rate of sludge application for a particular parcel of land, the objective shall be to match as closely as possible the quantity of nutrients removed from the soil by the harvesting of the crop. The allowable rate will thus be determined by the nutrient uptake capabilities of the particular crop under consideration.

The sludge hauling contractor shall adhere to the application rate (in cu. yd./A/yr.) specified in the Certificate of Approval issued by the Waste Management Branch of the Ministry of the Environment. The suitability of sludge application rates may if required be monitored by soil analyses and/or crop analyses. The collection of soil or crop samples shall be the responsibility of the Waste Management Branch.

4.2 The sludge shall be spread uniformly over the surface of the land.

4.3 The sewage treatment plant operating agency is to keep records of the location of all the sites used for the disposal of its sludge and the sludge quantities disposed of at each site, each week (eg. volume of sludge in cu. yds., and weight of sludge solids in tons). The operating agency shall ensure that at least every 3 months, samples of the sludge are submitted for thorough analysis (eg. total solids, volatile solids, pH, nitrogen, phosphorus, potassium, ether extractables, heavy metals, etc.).

APPENDIX I

Note: The following tables are extracts from the Ministry of Agriculture & Food's publication No. 29 entitled "Drainage Guide for Ontario".

Table I - Drainage Key for Soil Groups

Soil Group	Permeability	Slope	Typical Soil Type
1a	Slow	Level to depressional	Jeddo
1b		Level to undulating	Haldimand
1c		Undulating	Caistor
2a	Moderate	Level to depressional	Brookston
2b		Level to undulating	Brookston
2c		Undulating to rolling	Perth
3a	Moderately rapid	Level to depressional	Parkhill
3b		Level to undulating	London
3c		Undulating to rolling	Guelph
4a	Rapid	Level to depressional	Granby
4b		Level to depressional*	Wauseon
4c		Level to undulating	Brady
4d		Level to undulating*	Berrien
4e		Undulating to rolling	Fox
5		Bedrock at less than 2 ft.	Farmington
6		Organic Soils	Muck, Peat

* Clay at 6 feet or less

Table II - Index of Soil Series in Key

Series Name	Soil Group	Series Name	Soil Group	Series Name	Soil Group
L'Achigan	4c	Caledon	4e	Emily	3b
Alberton	2c	Caistor	1c	Englehart	4b
Allendale	4b	Camilla	3b	Evanturel	3c
Alliston	4d	Campbell	2c	Falardeau	2a
Almonte	2c	Cane	3a	Farmington	5
Ameliasburg	5	Carp	2c	Ferndale	2a
Ancaster	3c	Casey	3b	Flamboro	4a
Appleton	3c	Cashel	2c	Fonthill	4e
Atherley	2a	Castor	3b	Fox	4e
Bainsville	3a	Chesley	2b	Foxboro	3a
Balderson	3b	Chinquacousy	1b	Franktown	5
Bamford	4c	Christy	3a	Galesburg	3c
Bancroft	4e	Clyde	2a	Gananoque	2c
Bass	1b	Codrington	3b	Gerow	2a
Bastard	5	Colborne	4e	Gilford	3a
Battersea	2c	Colwood	3a	Gordon	2c
Beamsville	1a	Conover	2c	Granby	4a
Bearbrook	1a	Cooksville	5	Grenville	3c
Belmeade	1a	Coutts	3b	Grimsby	4e
Bennington	2c	Craigleith	1b	Guelph	3c
Berriedale	3c	Cramahe	4e	Guerin	3b
Berrien	4d	Crombie	3a	Gwillimbury	4c
Beverley	3b	Dack	1c	Haileybury	1c
Binbrook	1c	Dalton	4d	Haldimand	1b
Blackwell	2a	Darlington	3c	Hanbury	1b
Blanche	3c	Dawson	3c	Harkaway	3c
Bolingbroke	4c	Deloro	3c	Harriston	3c
Bondhead	3c	Doe	2a	Harrow	3c
Bookton	4d	Donnybrook	4e	Hendrie	4c
Brady	4c	Dumfries	3c	Henwood	4e
Brant	3c	Dummer	3c	Hillier	5
Brantford	2c	Dundonald	4d	Hillsburg	4e
Brethour	2a	Dunedin	1c	Himsworth	2a
Bridgman	4e	Dymond	3b	Hinchinbrook	3b
Brighton	4e	Eamer	3c	Honeywood	3c
Brisbane	4c	Earlton	3b	Howland	3b
Brockport	5	Eastport	4e	Huron	2c
Brookston	2a	Edenvale	4d	Innisville	3a
Brookston	2b	Eganville	3c	Jeddo	1a
Bucke	4d	Elderslie	2c	Kagawong	5
Burford	4e	Eldorado	3c	Kars	4e
Burnbree	5	Elk Pit	4e	Kemble	2c
Burnstown	3c	Elmbrook	2c	Kenabeek	4a
Burpee	4a	Elmsley	5	Killean	3b
Buzwah	2c	Embro	3b		

Table II - Continued

Series Name	Soil Group	Series Name	Soil Group	Series Name	Soil Group
King	2c	Nipissing	3b	St.Samuel	4a
Lambton	2c	Norham	3c	St.Thomas	4e
Lanark	2c	North Gower	2a	Sullivan	4e
Lansdowne	1b	Oneida	2c	Sutton Bay	3e
Leech	2c	Ontario	3c	Tavistock	2c
Lietrim	3c	Osgoode	3a	Thames	2b
Lieth	3c	Oshtemo	4e	Tennyson	3c
Lily	3a	Osnabruck	2a	Tecumseth	4c
Lincoln	1a	Osprey	3c	Teeswater	3c
Lindsay	2b	Otonabee	3c	Thorah	4c
Listowel	3b	Otterskin	4d	Thornloe	1a
Little Current	5	Parkhill	3a	Thwaites	2c
Lockport	5	Peat	6	Tioga	4e
London	3b	Peel	1c	Toledo	2b
Lovering	2b	Pelham	4e	Traflagar	5
Lyons	3a	Pense	2c	Trent	3b
Magnetawan	2c	Perch	1a	Tuscola	3b
Mallard	4c	Percy	3c	Tweed	3c
Malton	2a	Perth	2c	Uplands	4e
Manotick	4d	Petherwick	3a	Vars	3c
Maplewood	3a	Phipps	2a	Vasey	3c
Marionville	2a	Piccadilly	3b	Vincent	2c
Matilda	3b	Pike	1b	Vineland	3b
Medonte	2c	Pike Lake	3c	Wabi	3c
McCool	2c	Plainfield	4e	Waterloo	4e
Miami	3c	Pontypool	4e	Watrin	4a
Milberta	2a	Powassan	2a	Waupoos	2c
Mill	4a	Raglan	4e	Wauseon	4b
Milliken	3b	Renfrew	1c	Wayside	4c
Minesing	2b	Rideau	1a	Welland	1a
Mississauga	5	Rubicon	4c	Wemyss	3a
Monaghan	2c	Sargent	4e	Wendigo	4e
Monteagle	3c	Saugeen	2c	Wendover	1b
Moose	3a	Schomberg	2c	Westmeath	4e
Morley	1a	Shashawandah	5	Whitby	3b
Morrisburg	2c	Sidney	1a	White Lake	4e
Moscow	2a	Simcoe	2a	Whitfield	5
Mountain	4d	Smithfield	2c	Winona	4d
Muck	6	Smithville	1b	Wiarton	3b
Murray	3b	Snedden	2e	Woburn	3c
Napanee	1c	Solmesville	2c	Wolford	2c
Nelson	2c	South Bay	2c	Wolsey	2a
Newburgh	3c	Stafford	3b	Wooler	3c
Newcastle	2c	Stockdale	3a	Wyevale	4e
New Liskeard	2a	St. Peter	4e		
Niagara	1a	St. Rosalie	1a		

Canadian Printco Limited
Montréal
03KT. KE204-3-PO65 A